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ABSTRACT

Technical factors involved in the delivery of broadband information between a cable television (CATV) system head-end and subscriber terminals are discussed. Recommendations pertaining to the need for research in specified areas are given and a review of the system's hardware is provided, including details about device noise and distortion characteristics. A treatment of various types of trucking systems, including two-way configurations, is presented and attention is devoted to the applications of advanced communications techniques, encompassing digital transmission, multiple-access systems, and signal transmission via optical waveguides. The report concludes with a review and listing of standards and tests for the delivery system, including those set by the Federal Communications Commission (FCC) and the National Cable Television Association. (NCTA). (Author)

OT REPORT 73-13

A SURVEY OF TECHNICAL REQUIREMENTS FOR BROADBAND CABLE TELESERVICES

VOLUME 3

OT

U.S. DEPARTMENT OF COMMERCE/Office of Telecommunications

VOLUME 3
SIGNAL TRANSMISSION AND DELIVERY BETWEEN HEAD-END AND SUBSCRIBER TERMINALS

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FOREWORD

As information transfer becomes more important to all levels of society, a number of new telecommunication services to homes and between institutions will be required. Many of these services may require broadband transmission. The new services may, in part, evolve from those provided by cable television.

This is one of a series of reports resulting from a survey of the CATV industry and related technological industries. The survey identifies some of the important technical factors which need to be considered in order to successfully bring about the transition from the technical state of today's cable television and services to those new teleservices which seem to be possible in the future.

The current and future broadband capabilities of telephone networks are not discussed since they are described in many Bell Telephone Laboratory and other telephone company publications. Also, the tremendous load projected for common carrier telephone and data systems in voice and data communication suggest that two-way, interactive, broadband networks, not now in existence, may be required in addition to an expanded telephone network. The many aspects of economic viability, regulation, social demand, and other factors that must be considered before the expectation of the new teleservices can be fulfilled are not within the scope of these reports. These reports concentrate on technical factors, not because they are most important, but because they have been less considered.

A report about the state-of-the-art and projections of future requirements in a complete technology draws material from a vast number of sources.

While many of these are referenced in the text, much information has been obtained in discussions with operators, manufacturers, and consulting engineers in the CATV industry. Members of the National Cable Television Association, particularly, have been most helpful in providing information, discussing various technical problems, and in reviewing these reports.

Because of the substantial amount of material to be discussed, it was believed most desirable to present a series of reports. Each individual report pertains to a sub-element of the total system. However, since some technical factors are common to more than one sub-component of the system, a reader of all the reports will recognize a degree of redundance in the material presented. This is necessary to make each report complete for its own purpose.

The title of the report series is: A Survey of Technical Requirements for Broadband Cable Teleservices. The seven volumes in the series will carry a common report number: OTR 73-13. The individual reports in the series are sub-titled as:

A Summary of Technical Problems Associated with Broadband Cable Teleservices Development, OT Report No. 73-13, Volume 1.

Subscriber Terminals and Network Interface, OT Report No. 73-13, Volume 2.

Signal Transmission and Delivery Between Head-End and Subscriber Terminals, OT Report No. 73-13, Volume 3.

System Control Facilities and Central Processors, OT Report No. 73-13, Volume 4.

System Interconnections, OT Report No. 73-13, Volume 5.

The Use of Computers in CATV Two-Way Communication Systems, OT Report No. 73-13, Volume 6.

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SIGNAL TRANSMISSION AND DELIVERY BETWEEN HEAD-END AND SUBSCRIBER TERMINAL

R. B. Chadwick, R. A. Chandler, R. L. Gallawa, L. E. Wood*

ABSTRACT

This report is concerned with the delivery of broadband information between the system head-end and the individual subscriber terminals. Recommendations pertaining to the need for research in specified areas are given. A review of the system hardware is provided, including discussion of device noise and distortion characteristics. Treatment is given to various types of trunking systems, including two-way configurations. A discussion of the applications of advanced communications techniques is provided, covering digital transmission, multiple-access systems, and signal transmission via optical waveguides. Finally, a review and listing of standards and tests for the delivery system are given, including FCC and NCTA standards.

Key Words: Cable television, CATV amplifiers, CATV distribution, digital signal transmission, fiber optics, microwave links, TV technical standards.

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1 INTRODUCTION

This report describes the system for the delivery of the broadband television signals from the originating head-end to the subheads of the distribution system and then to the subscriber terminal.

This description includes a short review of present practice for the delivery of one-way service and discusses two-way delivery as it is presently conceived. In addition, new concepts for signal delivery such as optical fiber systems and the use of digital modulation techniques are explored and the relative advantages, disadvantages, and state of development are discussed.

Finally, a section on performance standards and tests for the delivery system describes the present performance criterion for CATV systems used to certify performance. The measurements required to satisfy the FCC technical requirements (sub-part 76K) and the recommendations for tests to satisfy these rules are given.

2 SUMMARY AND RECOMMENDATIONS

This report suggests several areas in need of additional technical attention. It is likely that the development of a vastly improved broadband communications industry will rely on this additional attention. This summary will briefly review the areas which relate to transmission and trunking aspects; specific recommendations will be included.

The problem areas fall into one of three categories: (1) commonality of terms and definitions, (2) system tests, and (3) application of advanced techniques. Each will be discussed in turn.

2.1 Commonality of Terms and Definitions

Many of the terms commonly used in the CATV industry have no common definition and a multiplicity of standards describing the definitions frequently exists. For example, some manufacturers distinguish between distribution amplifiers and line-extending amplifiers according to their operating levels. Other manufacturers use the term "distribution amplifier" to describe their bridging devices. Additionally, trunk amplifiers are known by various terms, including "main station" and "line amplifier." We recommend that attention be given to eliminating these incongruities.

In the same category is the fact that a clearly-specified definition of signal-to-noise ratio should be instituted, especially with respect to thermal noise measurement bandwidth and temperature. It should also be made certain whether a specified video signal is to modulate the carrier while the signal level at the sync tips is being measured. The relation of the system signal-to-noise ratio to the signal-to-noise ratio measured at the camera should also be made clear, and an explicit relation between baseband and RF signal-to-noise ratio should be specified. Those familiar with the industry recognize that many other examples can be given. This situation should be corrected as rapidly as possible through cooperation of the industry, the professional organizations, and the government.

2.2 System Tests

The determination of performance of an assembled and installed delivery system is still considered by many to be an art instead of a science. Instrumentation and system design which permit accurate performance evaluation should be explored. Many of the problems stem from a lack of appropriate test procedures and test instrumentation to properly evaluate in a quantitative way the capability of the system to deliver an acceptable signal. This is true for both the upstream and the downstream channels.

The cascadability of amplifiers is presently limited not by the dynamic range of the amplifiers, but by how well the system can be equalized. Techniques for improving the equalization, including methods for field alignment, should be explored.

The question of overload levels in the distribution amplifiers also arises. The advantages of high operating levels on the distribution systems are obvious. It appears, however, that to maintain these levels, the distribution amplifiers are operated at or near their individual overload levels. Clearly, gain setting errors could conceivably cause the amplifiers to be driven into overload, where distortion products increase more rapidly with increasing level than in the normal dynamic range. If this high operating level does lead to noticeable distortion at the receiver terminal, it may be well to investigate the feasibility of reducing amplifier third-order curvature without a disproportionate cost increase.

There are several definitions of cross modulation, some of which are qualitative. A consistent definition should be adopted by the industry. Test procedures for measurement should also be standardized.

At present, no practical way appears to test the AGC performance of an installed system. Field tests should be devised which will assure that the AGC is operating within specification limits.

Test instruments normally used for measuring signal level within a system have an accuracy which is no better than ± 2 dB, yet signal deviations of greater than ± 0.1 dB in each of the amplifiers can cause serious signal degradation on the system. Signal level measurement techniques capable of testing an individual amplifier should be devised.

Differential phase and gain and group delay measurement techniques should be developed and instrumentation be made available at reasonable cost.

Simpler tests for meeting "proof of performance" requirements should be devised. An extremely promising technique would be to take photographs of a "standard" TV presentation under controlled conditions and then these images would be processed either digitally or optically to determine if the system is performing properly. The advantage here is that the system operator need purchase no special-purpose equipment, since only a "standard" TV set and an ordinary photographic camera would be required.

The careful analysis of the most effective method for delivery of a limited number of television channels of widely separated rural subscribers has not been performed at present. The many available alternatives should be examined for feasibility, and test programs to evaluate designs intended for this purpose should be conducted.

2.3 Application of Advanced Techniques

Digital methods will reduce the requirements on the channel signal-to-noise ratio and the required dynamic range of the system, as shown in this Volume. This represents a potential reduction in system cost. But, due to the large number of existing TV sets, it is unlikely that digital techniques will be used in the near future for TV signals into the home; however, digital techniques should prove vastly superior to analog techniques in distributing from head-ends to subhead-ends. The greatest opportunity and necessity for digital techniques in the future seems likely to be in the two-way systems and services. Design ideas and philosophies for two-way systems are just now being developed, and it is important that future two-way systems be capable of meeting the demands of a complex society. It is likely that these demands will be more readily satisfied by systems with both voice and data upstream capability rather than by systems with data capability only. An effort is needed to determine several system types which will provide upstream voice capability and determine relative merits of each and then construct an experimental system.

The advantages of using glass fiber waveguides and optical sources, in lieu of coaxial cables and conventional electromagnetic signal sources, are listed and discussed in the main body of this report. The advantages include: size, weight, flexibility, lack of electromagnetic leakage, environmental factors, electrical isolation, and potential cost.

The economics of glass waveguides are not yet clearly defined. In the text we discuss an economic study which was conducted in the United Kingdom; that study is now deficient in two respects; first, it is two years old and the economic picture has changed dramatically in those two years; second, the study was appropriate only to the U.K. A similar study is needed in this country to weigh today's urban and rural needs against the viability and utility of these advanced techniques. We also see a need for further engineering study of some of the technical problems remaining in the use of the proposed glass waveguides. Methods of joining fibers, for example, must be improved in order to make it simpler and more efficient. Coupling energy into and out of the fiber is now an art, more or less, and additional study is needed to refine the techniques. Finally, possibilities in space multiplexing have not been examined with regard to fiber bundles. We know that hundreds of fibers can be put into a single jacketed bundle and that each fiber can support hundreds of megabits/sec (and perhaps even gigabits/sec).

3 COMPONENTS OF THE DELIVERY SYSTEM

3.1 Amplifiers

Probably the most critical single item in the CATV trunk distribution system is the amplifier. It is this device that is required to correct for the deficiencies and the uncertainties of the other system components. The required goal of any cable system is to provide a signal of specified level at a series of user terminals, with each signal-to-noise ratio above or equal to an established minimum. The system amplifiers must meet these requirements while correcting for variable and nonuniform environmental factors - especially temperature - and, at the same time, they must contribute a minimal amount of noise and various distortion products.

The amplifiers involved in the CATV distribution system fall into three general categories: trunk, bridging, and distribution.

Trunk amplifiers are used on the main trunkline as repeaters; they are intended to compensate for the losses of adjacent lengths of cable; hence, the spacing between trunk amplifiers is commonly given in decibels instead of in units of physical length.

User terminals are never fed directly from the main system trunk. Bridging amplifiers are used to provide isolation between the main trunk and the trunk-bridger combinations are amplifiers serving the dual purpose of main-trunk repeating and coupling to a distribution line. Intermediate bridgers are amplifiers which drive distribution lines but which provide no main-trunk gain.

A single bridging amplifier may drive several distribution lines; thus, it must be capable of providing a specified level to each distribution line while compensating for the isolation loss.

Distribution amplifiers are applied as repeaters on the distribution lines. They must compensate for cable losses as well as the losses introduced by the directional taps or couplers to which the individual user terminals are attached. Performance requirements for these devices are generally less exacting than those for the main-trunk amplifiers.

3.1.1 Automatic Gain and Slope Control

Signal attenuation by coaxial transmission lines is a function of both temperature and frequency. Cable attenuation varies typically about 1% for a 5°C temperature change (Rheinfelder, 1972), or 0.11% for a 1°F change. For a normal ambient value of 60°F, the temperature range -40°F to +140°F corresponds to attenuation errors of -11% to +9%. For a trunk amplifier spacing of 20 dB, this temperature range implies a change in electrical length of -2.2 dB to +1.8 dB. Automatic gain control (AGC) is used in trunk line amplifiers to compensate for these temperature variations. System economics are such that AGC is not usually included in each trunk amplifier; actual spacing of the AGC amplifiers is determined by the expected range of temperature variation and the dynamic range of the AGC circuitry of the amplifiers to be used. Although some systems may require inclusion of AGC in every trunk amplifier, many others may need it only every third or even every sixth or seventh device.

A single channel may be used for gain determination, although the use of a pilot carrier frequency is commonly employed. Typically, this frequency lies just above the FM broadcast region (88-100 MHz) or just above Channel 13 (210-216 MHz). The exact frequency is generally optional, depending upon the supplier, although 223.25 MHz appears to be the most widely used frequency.

Cable attenuation is also frequency-dependent. The standard VHF 12-channel split-band system ranges over two octaves - from 55.25 MHz to 211.25 MHz (video carriers for Channel 2 and Channel 13, respectively). A typical 25-dB length of cable (meaning that the cable length is sufficient to attenuate the highest video carrier - say that of Channel 13 - by 25 dB) might attenuate the Channel 2 video carrier by only 12 dB. This 13-dB difference in levels is called <u>tilt</u>.

A system whose trunk amplifier gains are set such that all channels are at equal levels at the amplifier inputs is said to be fully tilted, or operated in the <u>full-tilt</u> mode. Clearly, for this case the amplifier outputs are maximally tilted. In the <u>half-tilt</u> mode, the gains are set such that the channel levels are equal at mid-span (the point halfway between adjacent trunk amplifiers). A third mode is block-tilt, where the low-band (Channel 2 through Channel 6) frequencies are set at a uniform level (e.g., 5 dB) below the high-band channels, which are also at a uniform level. The _flat_ mode has all channels at a uniform level at the amplifier outputs; in this case, the inputs are maximally tilted.

Since cable quality is nonuniform, and since tilt may be varied with temperature change, it is necessary to include an automatic slope compensation in a system. (The distinction between tilt and slope should be emphasized at this point. Tilt refers to difference in levels between channels, while slope refers to a difference in gains between channels.)

Automatic slope control (ASC) is typically effected by monitoring the levels of a low-band and a high-band frequency and applying the error signal to the slope-contolled amplifier to restore the desired tilt. Standard video carriers are sometimes used for control, while some manufacturers prefer to use separate pilot carriers.

A single pilot-tone or single-channel AGC scheme may also provide a degree of tilt control by compensating the gain control for a range of frequencies. With the application of this control, response changes with gain.

3.1.2 Noise and Distortion Products

Cable length is limited primarily by thermal noise and nonlinear amplifier characteristics, both of which degrade output signal quality. In Section 6, the use of different modulation techniques is considered as a technique to extend trunk length. The way that a cascaded amplifier system degrades channel signal-to-noise ratio is considered below.

In a cascade of m amplifiers, each having a noise figure F_a and each being separated by a cable with an associated equalizer, the overall noise figure F_o is given by

$$F_o = mF_a \quad .$$

Because the cable loss has been equalized, this is independent of frequency. An implied assumption here is that the first element in the cascade is an amplifier rather than a cable equalizer section. The signal-to-thermal-noise ratio after m amplifiers can be calculated using the definition of noise figure,

$$F_o = \frac{SNR_{in}}{SNR_m}$$

where SNR_{in} is the signal-to-thermal-noise ratio at the input to the first amplifier, and SNR_m is the signal-to-thermal noise ratio after the m^{th} amplifier. Clearly, the signal-to-thermal-noise ratio is degraded by each additional amplifier in the cascade so that system length degrades performance.

There are other types of noise and, to illustrate how the output signal-to-noise ratio is calculated, consider the basic system shown in Fig. 1. The signal-to-camera-noise ratio, SNR_c, is nominally 50,000 (47 dB) and the input signal to the first amplifier is approximately 1 mV across 75 ohms. The thermal noise power, n_w^2, into the first amplifier is given by kTB, where k is Boltzman's constant (1.38×10^{-23} joule/°K), T is room temperature (290°K), and B is the bandwidth (4.5 MHz).9 Thus, the input signal-to-thermal-noise ratio, SNR_{in}, is 10^6 (60 dB). The output signal-to-noise ratio after m amplifiers is given by

$$SNR_m = \frac{1}{(SNR_c)^{-1} + mF_a(SNR_{in})^{-1}}$$

This expression shows that generally when m is small, the first term in the denominator dominates and the signal-to-noise ratio is approximately that of the TV camera. As m becomes larger, the second term dominates and the signal-to-noise ratio then begins to decrease with increasing m. For the numbers here and an amplifier noise figure of 10 (10 dB), the threshold where the denominator terms are equal occurs at m = 2 and the signal-to-noise ratio after 10 amplifiers is 10^4 (40 dB). The important point is that the quality of the output signal depends on both the head-end

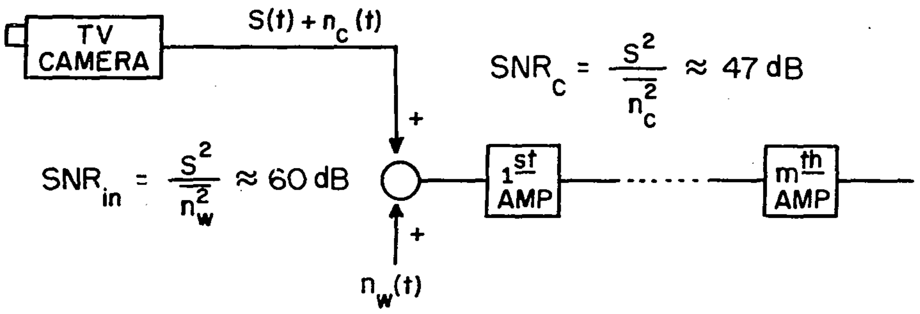

Figure 1. Basic CATV System Diagram for Noise Calculation.

equipment and on the transmission system, and the worst of these two will determine the performance.

Thus, for a specified output signal-to-noise ratio performance, a lower bound exists for input signal level. An upper limit also exists for output signal level, and is due to nonlinear amplifier characteristics. If this upper bound is exceeded, certain distortion products become so prevalent as to cause objectionable patterns to appear on the subscribers' television screen. The degree of objectionability associated with various distortion levels is, of course, subjective, and has been studied in detail and reported by TASO.

It is common practice to represent amplifier transfer characteristics as a power series. For devices operated below overload, this series may be truncated after the cubic term with negligible loss in accuracy, and the second- and third-order terms are manifested in system performance as intermodulation products. Most of these products are sum and difference frequencies of carriers and are classed under the heading of _intermodulation distortion_. Second-order intermodulation distortion arises from the quadratic term in the amplifier transfer function, and most of the sum and difference products generated by the cubic term account for third-order intermodulation distortion. In the cascaded system, these second- and third-order intermodulation products increase as the number of amplifiers increases. Additionally, intermodulation distortion increases one dB for each one-dB increase in output level.

Reduction of intermodulation distortion (second-order) is effected both by minimizing the coefficients of the second- and third-order terms in the amplifier transfer function and by judicious carrier spacing. The twelve-channel, split-band, frequency allocations are such that the video carriers are free of any second-order products. However, a high-capacity system operating with twenty to forty channels must endure a multitude of second- and third-order beats (see Table 1).

The amplifier state of the art is such that third-order beats at a nominal operating level of 32 dBmV are suppressed typically to a level of about -100 dB relative to the desired video carrier in a 21-channel system. Second-order beats for a single-ended amplifier are generally at -71 dB with respect to carrier level. Push-pull devices improve the second-order figure to around -80 dB; this improvement is at the expense of a cost increase of about 20%.

These third-order products, which do not contribute to intermodulation distortion, have much more serious effects on individual amplifier and, ultimately, system operating levels. These are the A+B-C and 2A-B products, where A, B, and C are any three of the system video carriers, and their

CHAN. #	VID. FREQ. MHz	BEAT FREQ. MHz	CHANS. BEATING
T-7	7.0	-0.5	½ T8
		-1.0	T8-T7, T9-T8, T10-T9, T11-T10, T12-T11, T13-T12, 3-2, 4-3, 6-5, B-A, C-B, D-C, E-D, F-E, G-F, H-G, I-H, 7-I, 8-7, 9-8, 10-9, 11-10, 12-11, 13-12, J-13, K-J, L-K, M-L, N-M, O-N, P-O, Q-P, R-Q, T-S.
		0 Beat	S-R
		+2.5	½ T9
T-8	13.0	-0.5	½ T10
		-0.75	2-T13
		-1.0	T9-T7, T10-T8, T11-T9, T12-T10, T13-T11, 4-2, C-A, D-B, E-C, F-D, G-E, H-F, I-G, 7-H, 8-I, 9-7, 10-8, 11-9, 12-10, 13-11, J-12, K-13, L-J, M-K, N-L, O-M, P-N, Q-O, R-P.
		-3.0	5-4
		0 Beat	S-Q, T-R
		+1.0	2×T7
		+2.5	½ T11
T-9	19.0	-0.75	2-T12, 3-T13
		-1.0	T10-T7, T11-T8, T12-T9, T13-T10, D-A, E-B, F-C, G-D, H-E, I-F, 7-G, 8-H, 9-I, 10-7, 11-8, 12-9, 13-10, J-11, K-12, L-13, M-J, N-K, O-L, P-M, Q-N, R-O.
		-3.0	5-3, 6-4
		0 Beat	S-P, T-Q
		+1.0	T7+T8
		+2.5	½ T13
T10	25.0	-0.75	2-T11, 3-T12
		-1.0	T11-T7, T12-T8, T13-T9, 4-T13, E-A, F-B, G-C, H-D, I-E, 7-F, 8-G, 9-H, 10-I, 11-7, 12-8, 13-9, J-10, K-11, L-12, M-13, N-J, O-K, P-L, Q-M, R-N.
		-3.0	5-2, 6-3
		0 Beat	S-O, T-P
		+1.0	2×T8, T7+T9
		+2.625	½ 2
T11	31.0	-0.375	½ 3
		-0.75	2-T10, 3-T11, 4-T12, 5-A.
		-1.0	T12-T7, T13-T8, F-A, G-B, H-C, I-D, 7-E, 8-F, 9-G, 10-H, 11-I, 12-7, 13-8, J-9, K-10, L-11, M-12, N-13, O-J, P-K, Q-L, R-M.
		0 Beat	S-N, T-O
		+1.0	T8+T9, T7+T10
		+2.625	½ 4
T12	37.0	-0.75	2-T9, 3-T10, 4-T11, 6-A
		-1.0	T13-T7, G-A, H-B, I-C, 7-D, 8-E, 9-F, 10-G, 11-H, 12-I, 13-7, J-8, K-9, L-10, M-11, N-12, O-13, P-J, Q-K, R-L.
		-2.75	5-T13
		0 Beat	S-M, T-N
		+1.0	2×T9, T8+T10, T7+T11, A-6
		+1.625	½ 5
T13	43.0	-0.75	2-T8, 3-T9, 4-T10
		-1.0	H-A, I-B, 7-C, 8-D, 9-E, 10-F, 11-G, 12-H, 13-I, J-7, K-8, L-9, M-10, N-11, O-12, P-13, Q-J, R-K.
		-1.375	½ 6
		-2.75	5-T12, 6-T13
		0 Beat	S-L, T-M
		+1.0	T9+T10, T8+T11, T7+T12, A-5, B-6
		+3.25	5-T11, 6-T12
2	55.25	-0.25	S-J, T-K
		-1.0	3-T7, 4-T8
		-1.25	A-4, 7-A, 8-B, 9-C, 10-D, 11-E, 12-F, 13-G, J-H, K-I, L-7, M-8, N-9, O-10, P-11, Q-12, R-13.
		-3.0	5-T10, 6-T11
		+0.75	T9+T12, T8+T13, C-5, D-6
3	61.25	-0.25	S-13, T-J
		-1.0	4-T7
		-1.25	A-3, B-4, 8-A, 9-B, 10-C, 11-D, 12-E, 13-F, J-G, K-H, L-I, M-7, N-8, O-9, P-10, Q-11, R-12.
		-3.0	5-T9, 6-T10
		+0.625	½ A
		+0.75	2×T11, T10+T12, T9+T13, D-5, E-6
		+1.0	T7+2
		+2.375	½ B
4	67.25	-0.25	S-12, T-13
		-0.625	½ C
		-1.25	A-2, B-3, C-4, 9-A, 10-B, 11-C, 12-D, 13-E, J-F, K-G, L-H, M-I, N-7, O-8, P-9, Q-10, R-11.
		-3.0	6-T9
		+0.75	T11+T12, T10+T13, E-5, F-6
		+1.0	T8+2, T7+3
		+2.375	½ D
		+3.0	5-T7, 6-T8
5	77.25	-0.25	S-10, T11
		-1.0	6-T7
		-1.625	½ F
		-3.0	T9+2, T8+3, T7+4
		-3.25	2×T12, F-5, G-6
		+0.75	C-2, D-3, E-4, 11-A, 12-B, 13-C, J-D, K-E, L-F, M-G, N-H, O-I, P-7, Q-8, R-9.
		+1.0	A-T13
		+1.375	½ G
		+2.75	T12+T13, H-6, G-5
6	83.25	-0.25	S-9, T-10
		-1.625	½ H
		-3.0	T10+2, T9+3, T8+4
		+0.75	D-2, E-3, F-4, 12-A, 13-B, J-C, K-D, L-E, M-F, N-G, O-H, P-I, Q-7, R-8.
		+1.0	A-T12, B-T13, T7+5
		+1.375	½ I
		+2.75	2×T13, H-5, I-6
		+3.0	T11+2, T10+3, T9+4
A	121.25	-0.25	S-F, T-G
		-0.625	½ N
		-1.0	B-T7, C-T8, D-T9, E-T10, F-T11, G-T12, H-T13 T13+5, T12+6
		-1.25	7-2, 8-3, 9-4, N-A, O-B, P-C, Q-D, R-E.
		+0.75	11-5, 12-6
		+1.25	2×3, 2+4
		+2.375	½ O
B	127.25	-0.25	S-E, T-F
		-0.625	½ R
		-1.0	C-T7, D-T8, E-T9, F-T10, G-T11, H-T12, I-T13, T13+6
		-1.25	8-2, 9-3, 10-4, O-A, P-B, Q-C, R-D.
		+0.75	12-5, 13-6
		+1.0	T7+A
		+1.25	3+4
		+2.375	½ Q
C	133.25	-0.25	S-D, T-E
		-0.625	½ R
		-0.75	2+5
		-1.0	D-T7, E-T8, F-T9, G-T10, H-T11, I-T12, 7-T13
		-1.25	9-2, 10-3, 11-4, P-A, Q-B, R-C.
		+0.75	13-5, J-6
		+1.0	T8+A, T7+B
		+1.25	2×4
		+2.675	½ S
D	139.25	-0.125	½ T
		-0.25	S-C, T-D
		-0.75	3+5, 2+6
		-1.0	E-T7, F-T8, G-T9, H-T10, I-T11, 7-T12, 8-T13
		-1.25	10-2, 11-3, 12-4, Q-A, R-B.
		+0.75	J-5, K-6
		+1.0	T9+A, T8+B, T7+C, 7-11
E	145.25	-0.25	S-B, T-C
		-0.75	4+5, 3+6
		-1.0	F-T7, G-T8, H-T9, I-T10, 7-T11, 8-T12, 9-T13
		-1.25	11-2, 12-3, 13-4, R-A.
		+0.75	K-5, L-6
		+1.0	T10+A, T9+B, T8+C, T7+D
F	151.25	-0.25	S-A, T-B
		-0.75	4+6
		-1.0	G-T7, H-T8, I-T9, 7-T10, 8-T11, 9-T12, 10-T13
		-1.25	12-2, 13-3, J-4.
		+0.75	L-5, M-6
		+1.0	T11+A, T10+B, T9+C, T8+D, T9+E
		+3.25	2×5
G	157.25	-0.25	T-A
		-1.0	H-T7, I-T8, 7-T9, 8-T10, 9-T11, 10-T12, 11-T13
		-1.25	13-2, J-3, K-4.
		+0.75	M-5, N-6
		+1.0	T12+A, T11+B, T10+C, T9+D, T8+E, T7+F
		+3.25	5+6
H	163.25	-1.0	I-T7, 7-T8, 8-T9, 9-T10, 10-T11, 11-T12, 12-T13
		-1.25	J-2, K-3, L-4
		+0.75	N-5, O-6
		+1.0	T13+A, T12+B, T11+C, T10+D, T9+E, T8+F, T7+G
		+3.25	2×6

Table 1. Second-Order Beat Products for Standard-Channel Assignments Between 7 MHz and 278.25 MHz. (Courtesy of Magnavox Co.)

CHAN. #	VID. FREQ. MHz	BEAT FREQ. MHz	CHANS. BEATING
I	169.25	-1.0	7-T7 8-T8, 9-T9, 10-T10, 11-T11, 12-T12, 13-T13
		-1.25	K-2, L-3, M-4
		+0.75	O-5, P-6
		+1.0	T13+B, T12+C, T11+D, T10+E, T9+F, T8+G, T7+H
7	175.25	-1.0	8-T7, 9-T8, 10-T9, 11-T10, 12-T11, 13-T12, J-T13
		-1.25	L-2, M-3, N-4, O-5
		+0.75	P-5, Q-6
		+1.0	T13+C, T12+D, T11+E, T10+F, T9+G, T8+H, T7+I
		+1.25	2+A
3	181.25	-1.0	9-T7, 10-T8, 11-T9, 12-T10, 13-T11, J-T12, K-T13
		-1.25	M-2, N-3, O-4
		+0.75	Q-5, R-6
		+1.0	T13+D, T12+E, T11+F, T10+G, T9+H, T8+I, T7+7
		+1.25	3+A, 2+B
9	187.25	-1.0	10-T7, 11-T8, 12-T9, 13-T10, J-T11, K-T12, L-T13
		-1.25	N-2, O-3, P-4
		+0.75	R-5
		+1.0	T13+E, T12+F, T11+G, T10+H, T9+I, T8+7, T7+8
		+1.25	4+A, 3+B, 2+C
		+1.75	S-6
10	193.25	-1.0	11-T7, 12-T8, 13-T9, J-T10, K-T11, L-T12, M-T13
		-1.25	O-2, P-3, Q-4
		+1.0	T13+F, T12+G, T11+H, T10+I, T9+7, T8+8, T7+9
		+1.25	4+B, 3+C, 2+D
		+1.75	S-5, T-6
11	199.25	-0.75	5+A
		-1.0	12-T7, 13-T8, J-T9, K-T10, L-T11, M-T12, N-T13
		-1.25	P-2, Q-3, R-4
		+1.0	T13+G, T12+H, T11+I, T10+7, T9+8, T8+9, T7+10
		+1.25	4+C, 3+D, 2+E
		+1.75	T-5
		-0.25	S-4
12	205.25	-0.75	6+A, 5+B
		-1.0	13-T7, J-T8, K-T9, L-T10, M-T11, N-T12, O-T13
		-1.25	Q-2, R-3
		+1.0	T13+H, T12+I, T11+7, T10+8, T9+9, T8+10, T7+11
		+1.25	4+D, 3+E, 2+F
		-0.25	S-3, T-4
13	211.25	-0.75	6+B, 5+C
		-1.0	J-T7, K-T8, L-T9, M-T10, N-T11, O-T12, P-T13
		-1.25	R-2
		+1.0	T13+I, T12+7, T11+8, T10+9, T9+10, T8+11, T7+12
		+1.25	4+E, 3+F, 2+G
		-0.25	S-2, T-3
J	217.25	-0.75	6+C, 5+D
		-1.0	K-T7, L-T8, M-T9, N-T10, O-T11, P-T12, Q-T13
		+1.0	T13+7, T12+8, T11+9, T10+10, T9+11, T8+12, T7+13
		+1.25	4+F, 3+G, 2+H
		-0.25	T-2
K	223.25	-0.75	6+D, 5+E
		-1.0	L-T7, M-T8, N-T9, O-T10, P-T11, Q-T12, R-T13
		+1.0	T13+8, T12+9, T11+10, T10+11, T9+12, T8+13, T7+J
		+1.25	4+G, 3+H, 2+I

CHAN. #	VID. FREQ. MHz	BEAT FREQ. MHz	CHANS. BEATING
L	229.25	-0.75	6+E, 5+F
		-1.0	M-T7 N-T8 O-T9 P-T10, Q-T11 R-T12
		0 Beat	S-T13
		+1.0	T13+9, T12+10 T11+11, T10+12, T9+13, T8+J, T7+K
		+1.25	4+H 3+I, 2+7
M	235.25	-0.75	6+F, 5+G
		-1.0	N-T7, O-T8, P-T9, Q-T10, R-T11
		0 Beat	S-T12, T-T13
		+1.0	T13+10, T12+11, T11+12, T10+13 T9+J T8+K, T7+L
		+1.25	4+I, 3+7, 2+8
N	241.25	-0.75	6+G, 5+H
		-1.0	O-T7, P-T8, Q-T9, R-T10
		0 Beat	S-T11, T-T12
		+1.0	T13+11, T12+12, T11+13, T10+J, T9+K, T8+L T7+M
		+1.25	2×A, 4+7, 3+8, 2+9
O	247.25	-0.75	6+H, 5+I
		-1.0	P-T7, Q-T8, R-T9
		0 Beat	S-T10, T-T11
		+1.0	T13+12, T12+13, T11+J, T10+K, T9+L, T8+M, T7+N
		+1.25	A+B, 4+8, 3+9, 2+10
P	253.25	-0.75	6+I, 5+7
		-1.0	Q-T7, R-T8
		0 Beat	S-T9, T-T10
		+1.0	T13+13, T12+J, T11+K, T10+L, T9+M, T8+N, T7+O
		+1.25	2×B, A+C, 4+9, 3+10, 2+11
Q	259.25	-0.75	6+7, 5+8
		-1.0	R-T7
		0 Beat	S-T8, T-T9
		+1.0	T13+J, T12+K, T11+L, T10+M, T9+N, T8+O, T7+P
		+1.25	B+C, A+D, 4+10, 3+11, 2+12
R	265.25	-0.75	6+8, 5+9
		0 Beat	S-T7, T-T8
		+1.0	T13+K, T12+L, T11+M, T10+N, T9+O, T8+P, T7+Q
		+1.25	2×C, B+D, A+E, 4+11, 3+12, 2+13
		-1.0	T-T7
S	272.25	-1.75	6+9, 5+10
		0 Beat	T13+L, T12+M, T11+N, T10+O, T9+P, T8+Q, T7+R
		+0.25	C+D, B+E, A+F, 4+12, 3+13, 2+J
T	278.25	-1.75	6+10, 5+11
		0 Beat	T13+M, T12+N, T11+O, T10+P, T9+Q, T8+R
		+0.25	2×D, C+E, B+F, A+G, 4+13, 3+J, 2+K
		+1.0	T7+S

Table 1, Continued. (Courtesy of Magnavox.)

contribution to signal degradation is termed cross modulation distortion.

Where intermodulation distortion is a result of carrier-beat interference, cross-modulation distortion is a result of an undesired signal--as distinguished from carrier-modulating a desired carrier. Thus, the undesired signal appears as a sideband of the desired carrier and is unaffected by shifting the frequency of the carrier of the undesired information (Collins and Williams, 1961). Since the composite video signal is "downward modulated," the synchronizing pulse tips represent the maximum signal excursion and are, therefore, the most apparent interfering signals in the distorted video display and appear as vertical bars, commonly called the windshield-wiping effect.

In the cascaded system, cross modulation is especially critical. It has been noted that all second-order and most third-order products increase in the cascade as $10 \log_{10} m$, indicating that the phase of each product contributed by each amplifier differs among the amplifiers. The A+B-C and 2A-B products, however, are phase coherent in the cascade, and the cross-modulation level increases as $20 \log_{10} m$, or is said to add on a voltage basis.

Cross modulation is also a function of amplifier output level--it is proportional to the square of the output, hence, it increases 6 dB for a 3-dB increase in output level. This is true for amplifiers operated below overload; above the overload level cross modulation increases at a faster-than-square-law rate (Bennett, 1940).

It has been shown (Collins and Williams, 1961) that cross modulation may be expressed as

$$XM = XM_{ref} + 2\ (S_{ref} - S) - 10\ \log_{10}(N_c - 1)\quad ,$$

where

S_{ref} = reference output level x dBmV
XM_{ref} = cross modulation measured for two carriers operated at the reference level (dB)
S = amplifier output level (dBmV
N_c = number of channels.

(It should be inserted at this point that cross modulation is generally measured by modulating all but one channel of a system with a 15-kHz square wave at a depth of 100%. All of the channels are then passed through the amplifier under test, and the cross-modulation level is the depth of the unwanted modulation appearing on the original CW carrier.)

It was previously indicated that cross modulation (third-order) increases as 20 $\log_{10} m$ for a cascade of m amplifiers, and intermodulation increases as 10$\log_{10}$ m. Thus

$$XM_m = XM_{ref} + 2(S_{ref} - S) - 10\ \log_{10}(N - 1) - 20\ \log_{10} m$$

gives the cross-modulation level at the output of the m^th amplifier. This may be rewritten in terms of S, the output level after m amplifiers, as

$$S = K - 10\log_{10} m\ ,$$

where

$$K = 1/2\ XM_{ref} + S_{ref} - 5\ \log_{10}(N_c - 1)$$

Clearly, an upper limit has been imposed on the effective system dynamic range. This information, coupled with the lower-bound constraint imposed by the thermal noise level, enables us to determine the proper system operating level. Figure 2 illustrates the upper and lower limits on operating level imposed by distortion and noise.

3.1.3 Operating Level Determination

Amplifier operating gains are recommended by the individual manufacturers, but typically fall in the range 17-23 dB. The determination of optimum spacing has been made by several authors, especially Simons (1970). In the following example, device specifications used are typical of present day CATV trunk amplifiers. The actual system levels are determined only after minimum acceptable end-of-system

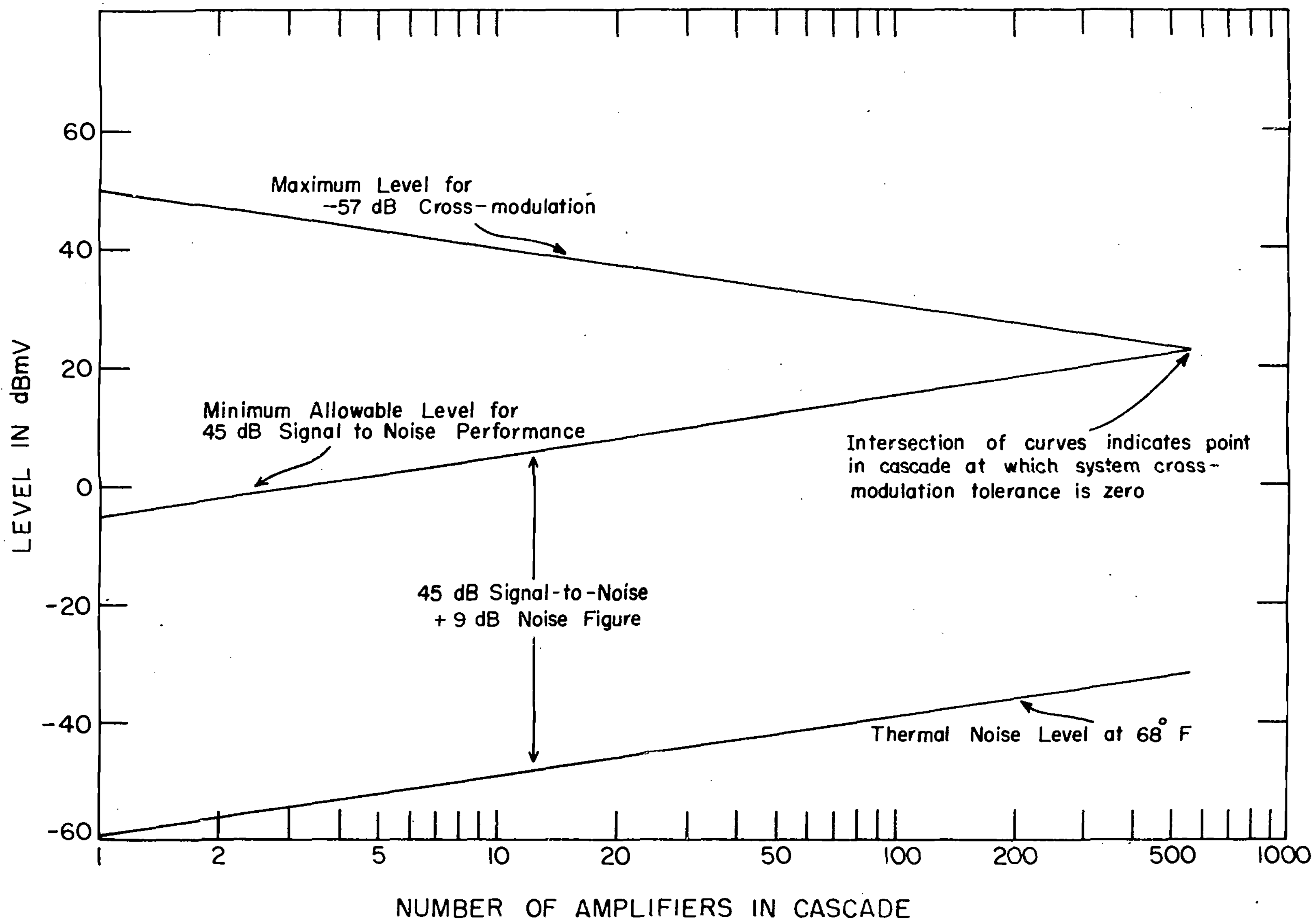

Figure 2. Limits on System Level Imposed by Crossmodulation and Thermal Noise.

signal-to-noise ratio and cross-modulation levels have been set.

It should be noted that, since subscriber terminals do not have infinite dynamic range, a range of acceptable input levels at the user's receiver must be included when the desired signal-to-noise ratio has been specified. It appears that the range 0 dBmV to 10 dBmV is adequate for most home receivers.

If we consider a system of identical cascaded amplifiers with noise figure 9 dB and cross modulation of -57 dB with 50-dBmV carrier levels, the equations for maximum output and minimum input signals may be plotted (for this example, N = 21, and the system objective for cross modulation is -57 dB and the desired end-of-system signal-to-noise ratio is 45 dB).

For m = 1, the minimum input could be -5 dBmV and the output could be as high as 50 dBmV. Restating this, the system length could be as much as 55 dB. For m = 10, the minimum input is +5 dBmV and the maximum output is 40 dBmV, leading to a maximum length of 10 x (40-5) = 350 dB. Thus, it is seen that reducing the gain of the individual amplifiers increases the system length. It can be shown that system length is maximized for individual amplifier gains of 8.68 dB. This optimum value, however, is determined for a system in which the signal levels are completely uniform, which may not be true for physical systems.

Uncertainties in system parameters cause uncertainties in the signal level throughout the system. This, in turn, causes a decrease in the system length. The problem of parameter uncertainty is discussed in Simons (1970). Simons develops Table 2, which is given below and shows the variation of optimum amplifier gain with amplifier uncertainty. A realistic value of amplifier uncertainty is 0.1 dB and the following table indicates that the optimum trunk amplifier gain is slightly in excess of 20 dB (optimum gain again being that gain for which system length is maximum).

Amplifier uncertainty dB	Optimum gain dB	Noise fig. dB	Maximum number of amplifiers
0.0	13.0	12.7	150
0.01	14.8	12.1	115
0.025	16.3	11.6	90
0.05	18.2	10.9	68
0.10	20.2	10.3	49
0.25	23.6	9.2	29
0.50	27.1	8.0	18
1.00	30.6	6.8	11

Table 2
Relationship among system uncertainties and maximum number of amplifiers in system. (Courtesy IEEE, from Simons, 1970.)

The values given assume an overload level of 50 dBmV. These figures are in very good agreement with currently used values of gain (22 dB) and noise figure (9-10 dB). (See Table 3, which shows typical characteristics of amplifiers.)

It appears that, in practical systems, maximum trunk cascades of no more than twenty amplifiers are most common (see Section 4); this practical limit results from tilt uncertainties in the system which are caused by equalizer errors. It is felt that equalizer design should be improved to remove this limitation, with some consideration given to whether additional equalization needs to be added to hold tilt errors to a minimum.

Considering the distribution portions of a CATV system, it is clear that, in addition to compensating for the frequency-dependent losses of an adjoining length of cable, the distribution amplifiers must also compensate for the so-called "flat" (frequency-dependent) loss of the directional taps and couplers used to couple the transmitted energy directly to the subscriber terminals. To minimize this loss, which is the insertion loss of the coupling device, the tap loss is increased (the tap loss may be expressed as the ratio of the input power of the device to the power at the tap output). But since the subscriber level must be held within certain limits, increased tap loss requires that the distribution level be increased. Clearly, reduced

Table 3. Typical amplifier parameters

	Trunk	Bridging	Distribution
Frequency Response & Response Flatness	50-250 MHz ± 0.25 dB	50-250 MHz ± 0.5 dB	50-250 MHz ± 0.5 dB
Minimum Full Gain (250 MHz)	26 dB	44 dB	25-50 dB
Operating Gain	22 dB	35-45 dB	25-45 dB
Gain Range, Manual	8 dB	8 dB	6 dB
AGC Compensation	± 0.5 dB out for ± 4 dB in	± 0.5 dB out for ± 4 dB in	
Slope Control	8 dB	8 dB	6 dB
Operating Levels, Typical			
Input	10 dBmV	10 dBmV	5-20 dBmV
Output	32 dBmV	45-50 dBmV	45-50 dBmV
Cross Modulation at Typical Output Level (21 channel)	-93 dB	-67 to -57 dB	-67 to -57 dB
Intermodulation at Typical Operating Level			
Second Order	-72 dB	-60 dB	-60 dB
Third Order	<-100 dB		
Maximum Output for -57 dB Cross Modulation (21 channels)	50 dBmV	50 dBmV	50 dBmV
Noise Figure	9 dB	9 dB	11 dB
Return Loss, Input and Output	16 dB	16 dB	16 dB
Hum Modulation	<-60 dB	<-60 dB	<-60 dB
Power Requirement	25-35 V ac rms 1 A	25-35 V ac rms .8 A	25-35 V ac rms .8A

insertion loss and increased level allows for more subscribers per amplifier.

Thus, we see that high distribution level is desirable. It should be pointed out that, although increased level implies shorter system length due to cross-modulation distortion, distribution cascades are typically very short--possibly two or three amplifiers--and are not limited by distortion considerations. While a typical twelve-channel system might be operated at a nominal trunk level of 25-35 dBmV, its distribution level will be generally from 40 to 50 dBmV.

3.1.4 Powering

Power is supplied to the system amplifiers via the cable. Off-cable power supplies accept the line voltage at 115 rms (nominal) and provide the cable with a 30- to 60-V rms regulated supply.

Current required per amplifier is usually no more than 1.2 A at 60V. The ac power is injected onto the cable through a power-inserter coupler, which includes filtering to isolate the ac line from the r-f signal.

The dc supplies for the amplifiers are located within the individual amplifier housings. Typically, they operate on either 30- or 60-V rms (nominal) levels, and require around 1 amp of current. Surge protection is usually built into the dc supplies, as is protection against static over-voltage damage. Some amplifiers include a provision for preventing the ac supply voltage from appearing at the output terminals.

3.1.5 Two-Way Systems

In the two-way CATV system a return path is provided for the signals originating at the subscriber terminal. The system amplifiers are subject to the constraints of the one-way system besides additional restrictions imposed by the two-way operation.

Actual device specifications for proper system operation are dependent upon the system configuration, e.g., a single-cable, mid-splitband system will have different device performance requirements than a multiple-cable system. It is not the purpose of this section to assess these various systems; some insight with regard to performance levels required in the different systems is given in Barnhart (1972) and Lambert (1971).

There are two major disturbances arising from two-way operation--group delay and loop feedback. Each appears in a given system to a degree of severity which may depend upon the system configuration, and it is instructive to determine, at least subjectively, the effects of each upon system performance.

System types for both one-way and two-way operation are given later and, in some two-way configurations, it is necessary to include high-pass/low-pass filters to steer the downstream and the return signals into the proper amplifiers. The gain-phase characteristics of these filters, especially near the pass-band limits, can cause unacceptable signal distortion. Fairly detailed discussions concerning group delay calculations and the effect of various types of filter response on group delay are given in Marron and Barnhart (1970).

Group delay is one of the most serious manifestations of the filter characteristic; the term describes the frequency-dependent delay of the modulation envelope. Excessive group delay is especially objectionable when color television signals are transmitted; it may also cause unacceptable distortion in data channels.

For the case of color television signals, recall that the chroma subcarrier is located nominally 3.58 MHz above the video carrier. A system with group delay will distort the signal such that the arrival of the chroma signal at the receiver will not coincide with that of the luminance signal. It has been shown (Barnhart, 1972) that "expert observers" would consider that 500 nanoseconds of chroma delay would impair reception, but not objectionably so. The same study indicates that a 230-nanosecond delay is something of a threshold value at which most observers notice perceptible distortion. A single good quality trunk amplifier may exhibit a worst-case chroma delay on the order of 10 nanoseconds. The multiplicative effects of cascading on delay must then be considered in the system design.

Filter gain and phase also enter unto the low-feedback problem. In any system where two directions of transmission are included on a single cable (many multi-cable two-way systems have at least one bidirectional cable), the combination of filters, return amplifiers, and downstream amplifiers form feedback systems. Recalling the Nyquist stability criterion, the loop gain must be such that the system gain falls below unity before the system phase shift reaches 180°, otherwise the system oscillates. Thus, the stopband gains of the filters must also be considered in design.

3.1.6 Device Specifications

Specification lists used to describe particular amplifier models include items of varying pertinence. Probably the most important performance parameters are output capability for a specified cross-modulation limit, noise figure, AGC (if included) and slope compensation range, flatness of response, second-order distortion (if the device is to be used on a system with more than the standard 12 channels), and input and output match, ordinarily listed as return loss.

All of the specifications are important, but such values as gain and frequency response are design constraints and typically would not be involved in a selection decision based on performance quality.

3.2 Cables

Transmission lines used on CATV systems must exhibit minimum attenuation due to radiation loss and conduction loss due to finite conductor and dielectric conductivity. It is well known that a coaxial transmission line constructed such that the ratio

$$\frac{r_o}{r_i} = 3.59$$

where

r_o = inner radius of outer conductor, and

r_i = radius of inner conductor,

has minimum attenuation (due to conductor loss) per unit length. This value of r_o/r_i gives an impedance of 76.7 ohms, assuming an air dielectric. Thus, 75-ohm cable is widely used and widely available.

Attenuation varies also with other than geometric parameters, most notably frequency. The attenuation below 300 MHz is due to conductor losses and varies with the square root of frequency. Above 300 MHz, the dielectric losses become significant and the frequency dependence is more complicated. In most cables the dielectric is not air, and the ratio r_o/r_i is increased to compensate for the greater-than-unity dielectric constant so that impedance is maintained at 75 ohms. Figure 3 shows the attenuation-vs.-frequency characteristics of a number of commonly used coaxial lines in the region where $f^{1/2}$ dependence is dominant. Note, for example, that the 0.412-inch foamed-dielectric cable varies in attenuation from 0.9 dB/100 ft at 54 MHz to 2.3 dB/100 ft at 216 MHz. This variation is termed the cable <u>slope</u>.

Cable attenuation also varies with temperature; a temperature change is manifested as a change in the effective electrical length of a cable. An industry rule of thumb holds that attenuation varies at the rate of 0.11%/F.

Compensating devices must be provided in an operating system to correct for the frequency and temperature dependence of the cable attenuation. These dependences may not be eliminated by more precise manufacturing techniques. Thermistor equalizers, tilt-compensated gain controls, and automatic slope amplifiers (covered elsewhere in this report) all correct, within limits, the predictable nonuniformities of the transmission lines. However, certain faults, especially reflection, cannot be eliminated.

As is well known from basic transmission line theory, any change in the characteristic impedance of a line will result in energy being reflected at the impedance

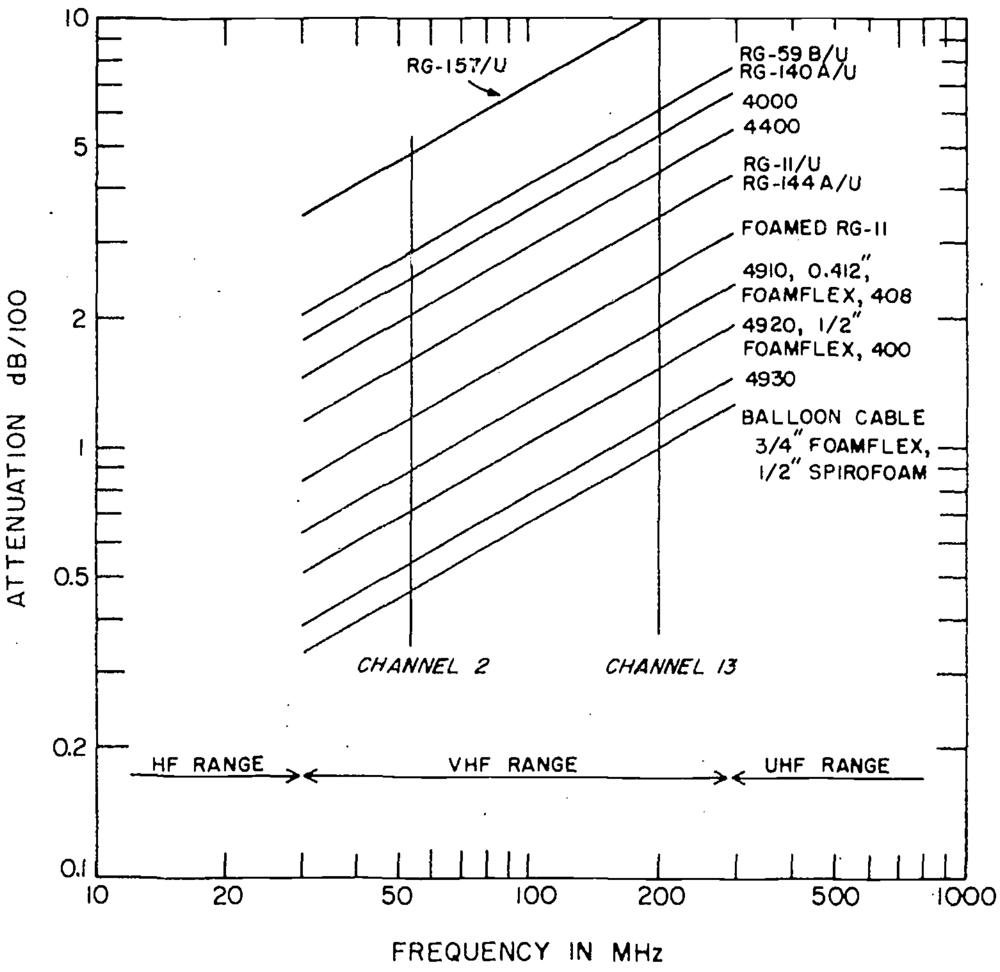

Figure 3. Attenuation of Coaxial Cables as a Function of Frequency. (Courtesy of Tab Books, from CATV System Engineering, 3rd Ed., Copyright 1970, by W. A. Rheinfelder.

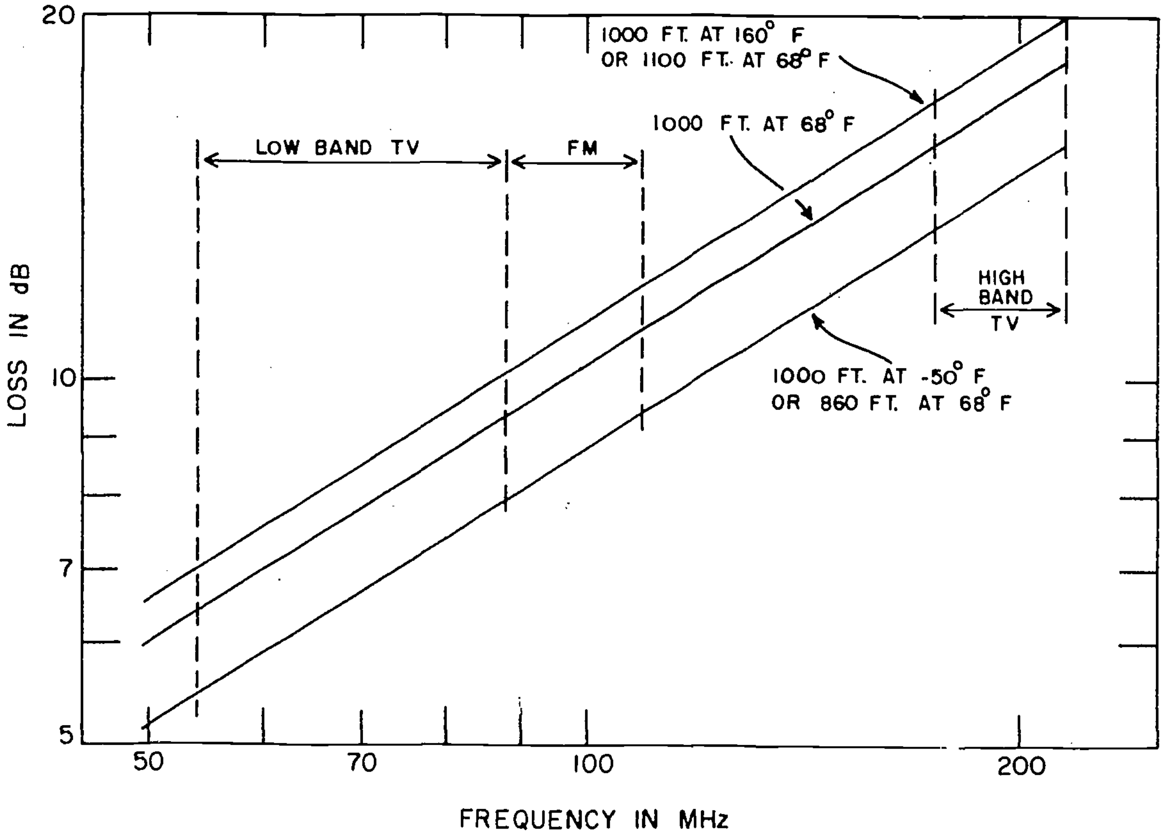

Figure 4. Effects of Temperature on Cable Losses. (Courtesy of Tab Books, from <u>CATV System Engineering</u>, 3rd. ed., Copyright 1970, by W. A. Rheinfelder.)

discontinuity. Any nonuniformity of conductor spacing within the line structure will cause a shift in characteristic impedance, as will any deformation of either conductor, such as a crimp in the outer conductor. Similarly, an impurity or fault in the cable dielectric will cause reflection.

The resulting loss is termed structural return loss, and is minimized in the manufacturing process. There are, however, other sources of reflection which result from the connection of the cable to other system devices. Cable connectors must be matched to the cable impedance or serious reflection will result.

If reflections are of sufficient magnitude, they will result in "ghosting" on the subscriber's television screen. The mechanism is simple: in a poorly-matched system, partially reflected energy returns to the transmitting end where it is again reflected if the transmitting end is not matched. The doubly-reflected component will arrive at the receiving end a finite time after the desired signal and will result in a double image, or "ghost," on the user terminal.

Usually the delay is small, so that the "ghosts" are not distinct, but rather the vertical edges of the picture are degraded. This could be corrected by using a nonlinear modulation technique, as discussed in Section 6, or by requiring better impedance matching. Perfect matches are not required; it must be kept in mind that the reflected signal will be attenuated by roughly twice the cable length. The reflection problem is considered in more detail in Section 3.3.

3.2.1 Cable Construction

Cable sizes are given as the outside diameter of the outer conductor; the three commonly supplied diameters for trunk and distribution cable are 0.412, 0.500, and 0.750 inches. Foamed dielectric (polyethylene) with relative permittivities of 1.5 and solid polyethylene dielectrics are almost universally used. Inner conductors are usually copper-jacketed aluminum, which offers the lower weight and cost of aluminum with the improved electrical performance of copper, assuming that the copper covering is many skin depths thick. Some cable, however, is supplied with solid copper center conductors. Outer conductors (shielding) are most commonly aluminum--either seamless tubing or wrapped aluminum sheeting with bonded overlap. A polyethylene jacket covers the entire assembly, providing good protection from moisture.

Although the electrically relevant items vary little among cable products, many varieties of elemental protection are offered; the choice is usually made among these with respect to application, e.g., steel armored cable may be desirable for buried-plant usage. Also, some cable designed for aerial use may include a "messenger" wire, which adds mechanical strength necessary for suspending amplifier and power supply modules.

Drop cable is ordinarily of the RG-59/U type, with braided or wrapped foil outer conductor and 20 or 22 AWG center conductors (usually solid copper). The foil type shielding is aluminum, while the braided types may use tinned copper, aluminum, or aluminum with copper coating. Messenger wires may be supplied with drop cable.

3.2.2 Radiated Interference to System

Early CATV systems were used solely where off-the-air reception was not adequate. Currently, residents of populated areas with one or more channels of good reception subscribe to obtain the program variety and other advantages offered by the cable service. In-band radiation from TV transmitters can present a serious interference problem. Correcting in-band pickup problems once the system is constructed may be difficult and expensive. The system initial design should give adequate consideration to shielding from radiation that is within the FCC limits not only from broadcast TV but from other types of transmissions. The severity of the problem, especially as cable systems expand, may be sufficient to warrant consideration of "undergrounding" the cable distribution.

The economics of this situation are not clear. Perhaps more of the main trunk lines will require use of a method of transmission which is less susceptible to direct pickup, such as microwave propagation or optical waveguides. Also, different types of modulation will be less susceptible to interference than is AM.

3.3 Taps, Splitters, and Matching Transformers

Subscriber drop cables are coupled to the system distribution lines through passive couplings called "taps." Two general types of taps are available--directional and pressure, although pressure taps are obsolescent and are increasingly less available than the direction-coupler type of device. A good tap should be well matched at the distribution line input and output, as well as at the tap outputs (a tap usually allows from 1 to 4 drop-cable connections). Pressure taps consist of a probe, which is inserted directly into the distribution line, and a matching transformer, which connects for the sending-end mismatch of the drop cable. The failing of this tap lies in the severe unpredictable system degradation introduced by the insertion of the probe into the distribution line.

Directional couplers which exhibit good matches (return loss of 20 dB or better) at all ports can be economically produced, and they are becoming more prevalent in CATV systems. A variety of tap values (tap output level relative to level at device input) is available to allow proper subscriber level with a minimum of unnecessary distribution loading. Tap values are usually offered in the range 10-35 dB in steps of 3 to 4 dB. Insertion losses corresponding to the range of tap values are roughly from 4 dB to 0.2 dB. Insertion loss flatness is normally ±0.3 dB over the frequency range 5-300 MHz.

As was parenthetically mentioned previously, minimum device return loss at all ports is ordinarily 20 dB. Isolation from tap output to device output (distribution line output) may range from 25 to 50 dB for the tap value range 10-35 dB. Isolation between tap outputs is generally 20 dB (the FCC requires a minimum of 18 dB between taps).

Power splitters are also available for applications where it is necessary to drive two or more additional drops from an initial drop. These devices typically have input return losses of 20 dB and tap isolation of around 30 dB. Tap loss, of course, is a function of the number of taps, usually 3.5 dB per tap for 2-output splitters, and is normally 7 dB per tap for 4-way devices. Note that the insertion loss appears in the output value for each tap due to device symmetry.

The drop cable receiving end is terminated at the subscriber terminal. Most home television receivers have 300-ohm balanced inputs; a balun must be inserted at the receiver terminals to match the 75-ohm unbalanced drop cable to the receiver impedance. These devices possess insertion losses of roughly 1 dB with a flatness of ±0.5 dB over the range 54-216 MHz. Input match is on the order of 14 dB return loss, and phase balance ranges from 25 dB to 40 dB for good quality units. Voltage blocking capacitors are also included to provide dc isolation of typically 500 volts.

Each termination of a cable segment should match the characteristic impedance of the cable, usually 73 to 75 ohms. If this condition is not met, some power is lost, but more important, the quality of the TV picture may be seriously affected. A cable termination which presents a mismatch in impedance causes a fraction of the signal power to be reflected in the reverse direction, or upstream, on the line. Reflected signals which travel back through a cable segment often become redirected into the downstream flow again and, in the process, experience a time delay relative to the direct signal that is proportional to the added distance traveled. These reflections can produce multiple images or ghosts in the subscriber's TV picture. The severity of the ghosting depends upon the relative strength of the delayed signal and the amount of delay. In general, the signals of short delay must be stronger to produce a perceptible ghost. As shown in Fig. 5, delays of

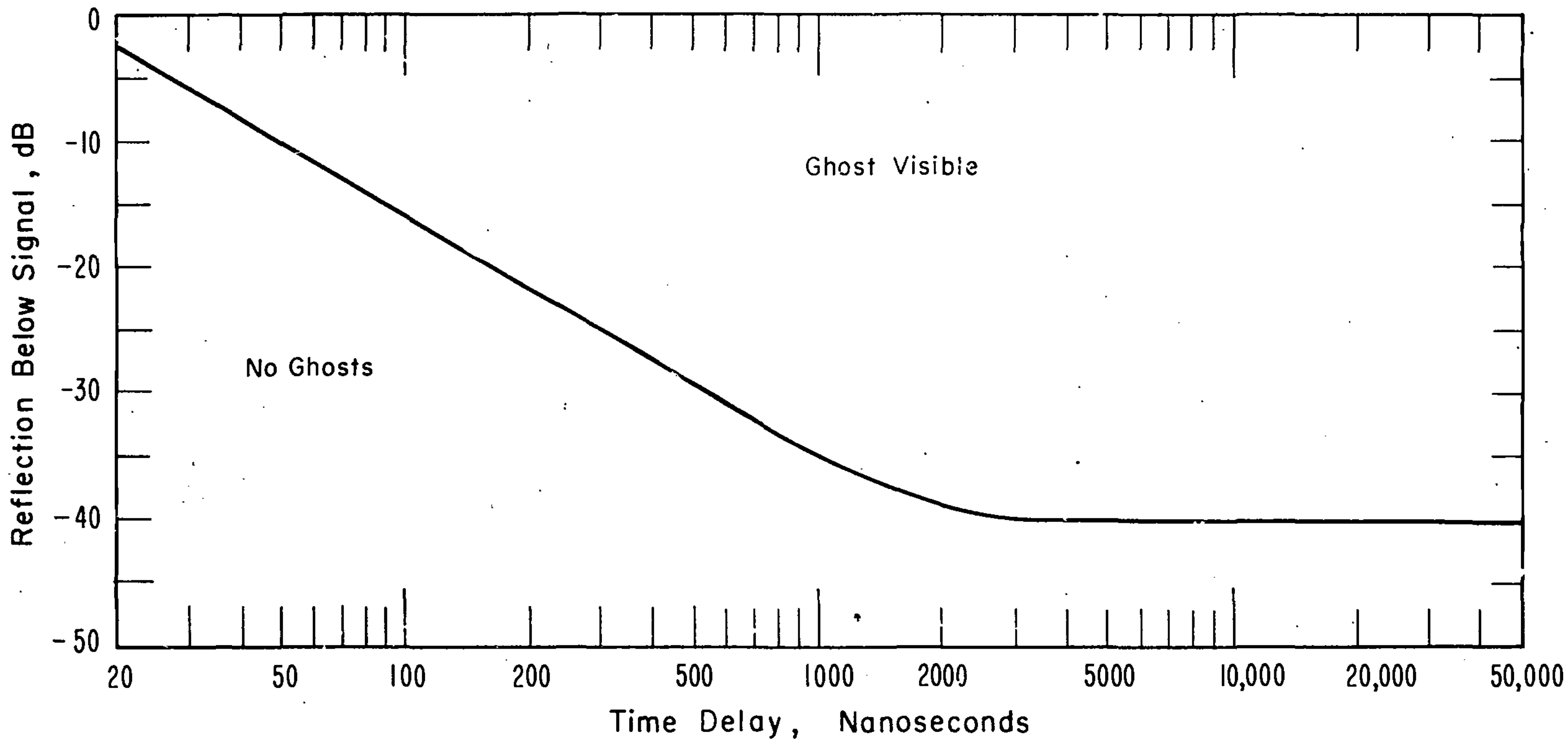

Figure 5. Multipath Perceptibility.

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100 ns (approximately 65' of cable) at a level of -16 dB relative to the direct signal are perceptible in the picture, while delays of 3000 ns (approximately 2000' of cable) need be only -40 dB to be seen. The longer delays would most likely be encountered in the main trunk lines. Reflections occur at trunk amplifiers due to mismatches, but present designs are such that these are small and usually do not produce a problem. In a well designed system, long delays may result from connector and cable deterioration through weathering. A simple reflection measurement can be made periodically at each trunk amplifier to detect such deterioration.

The most severe reflection problem in a CATV system occurs at the subscriber's TV set, as discussed in Volume 2. Not only does the receiver itself have a large excursion in impedance over the frequency range, but there is the need to transform the impedance up from the cable impedance (unbalanced 75 ohms) to 300 ohms (balanced) to accommodate the TV receiver. In addition, conditions at the subscriber's terminal are not controlled by the system designer, and additional receivers may be attached or accidental opens or shorts may appear on the cable. The impedance transformation can be accomplished with a broadband unbalanced-T to balanced-H resistive minimum-loss matching pads. This results is an attenuation of about 12 dB, which is quite high, but this means of matching has the advantage of isolating the reflections produced at the receiver. A serious drawback is that since the cable must extend into the subscriber's home the terminating pad may accidentally be disconnected, shorted, or otherwise tampered with. Should the termination be altered at the cable in the home, large reflections placed on the line could upset the picture quality of nearby subscribers. A more common means of impedance transforming is by a wideband transformer with losses not exceeding 0.5 dB. In this case, some degree of isolation of the termination within the home can be accomplished by the use of high-loss house drop cable, which has the added advantage of further reducing a double reflection from the drop cable feed termination back to the home receiver.

In a worst-case situation where the home terminal is open or shorted, all the power will be reflected back to the cable. Assuming a house drop of 150 feet of RG 59/U at the Channel 2 frequency, the reflected signal must experience an attenuation of 21 dB to the adjacent subscriber's output taps in order to prevent perceptible co-channel ghosting. The isolation required for Channel 13 is about 16 dB, less because of the increased attenuation in the cable. The total isolation necessary is more than can be sacrificed in an attenuation pad; therefore, relatively sophisticated directional couplers must be employed to offer low signal attenuation in the forward direction and high attenuation to the reflected signals. Directional couplers are available which provide up to about 20 dB tap-to-tap isolation and somewhat higher tap-to-input isolation. It seems likely that at times circumstances can exist in present CATV systems which will reduce picture quality due to ghosting. The subscribers may not be inclined to report the difficulty because they have been conditioned by past deficiencies with direct off-the-air reception. A system design to avoid all worst-case impedance matching problems would undoubtedly be very expensive; a better solution may be to educate the subscriber in preventing and recognizing these problems in the home.

4 TRANSPORTATION TRUNKS.

The system for delivery of service has been the concern of the CATV industry since its inception. Consequently, a great backlog of experience in the design and operation of systems for this type service presently exists within the industry, particularly for one-way delivery. Delivery systems can conveniently be broken into two parts. The first part is the so-called transportation trunk, which is required to deliver high-quality signals between two components of the system without directly serving subscribers. Examples of this service are between an outlying antenna site and a downtown hub or head-end, or between the main head-end and sub-head-end in the hub system. Figure 6 illustrates these examples. The second part is the delivery of the signal from the head-end to the subscriber terminal. This includes the trunking and distribution with its associated amplifiers and cables. Section 5 gives many examples of approaches to this part of the system.

4.1 Broadband Trunks

The hub concept for signal delivery is becoming widely accepted as the way to install systems, particularly in large metropolitan areas. In this approach, which is illustrated in Fig. 7 , the signals originate in a central head-end and are distributed through the transportation system or super-trunk to a number of sub-head-ends. From the sub-head-end the signals are delivered through the trunking and distribution system to the subscriber. The sub-head-end is significantly less sophisticated than the master head-end, but this node can serve for inserting programs of neighborhood interest or as the processing terminal in two-way applications. The most important feature, however, is the fact that by correct location of the sub-head-ends, the trunk and distribution to the customer is accomplished at a rather low level of cascading.

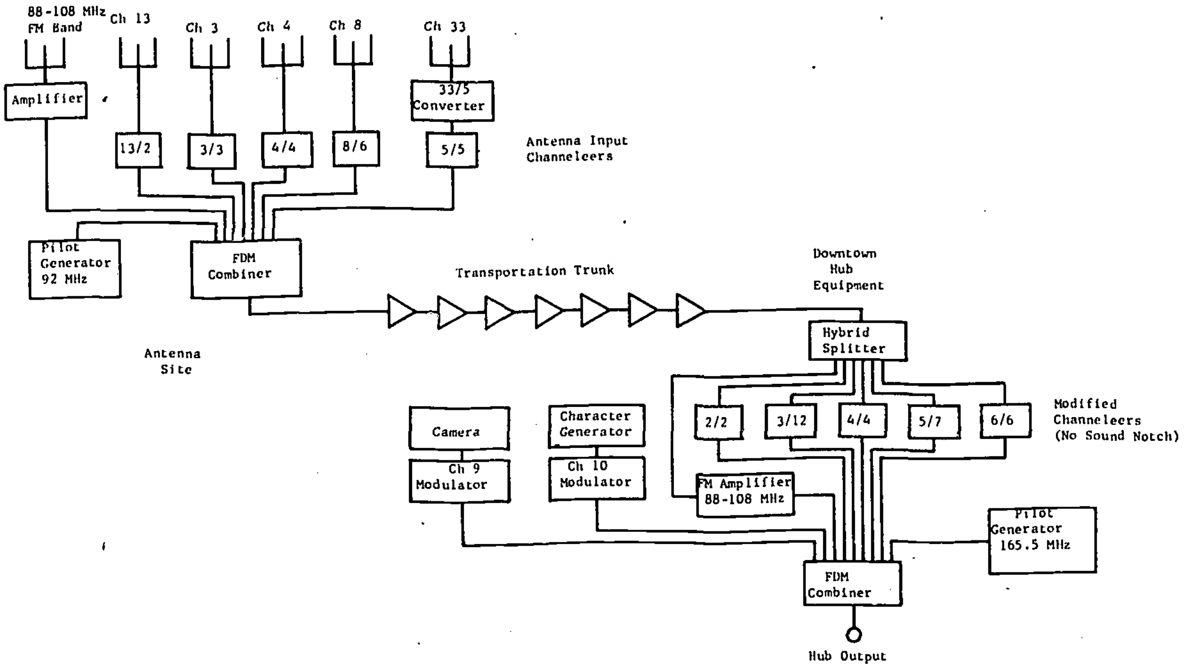


Figure 6. Application of Transportation Trunk Between Outlying Antenna Site and Head-End. (Courtesy IEEE, from Taylor and Janes, 1970.)

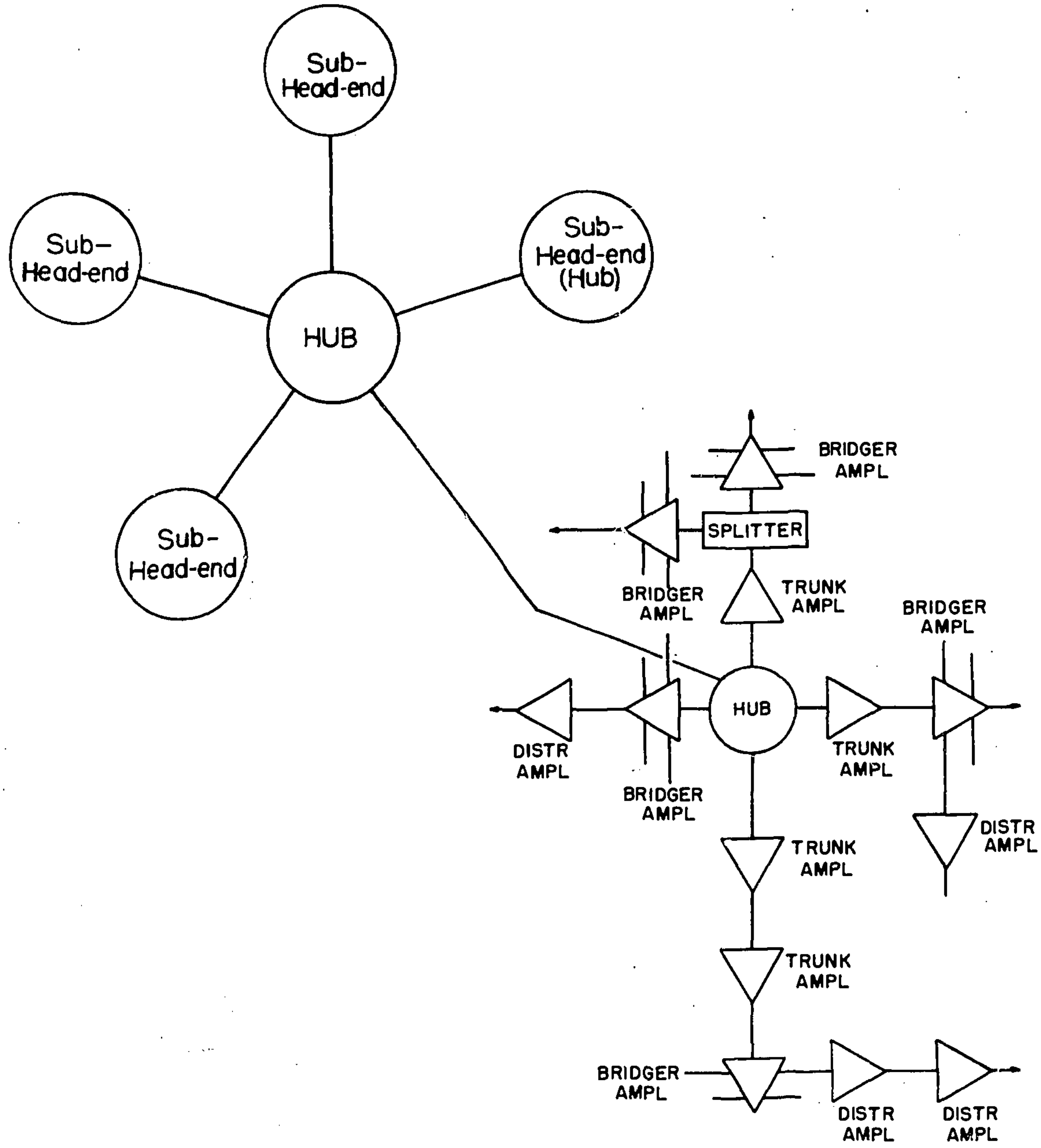


Figure 7. The Hub System Layout (EIE Comm. Bull., 1972). from Blanchard (1970).

A nominal cascade length using this approach is twenty amplifiers.

The trunking requirement can be satisfied by one of several methods, the most common being broadband transmission of the channels between 50 and 300 MHz. The second method uses the sub-low bands between 6 and 48 MHz and requires several cables for complete channel coverage. Another approach uses microwave links. Finally, a technique virtually unexplored, but one which offers many potential advantages, is digital modulation, discussed in Section 6.

Critical to the design of any trunking system is the number of channels to be distributed. In typical existing systems, these channels have tended to be the twelve FCC channels, with 54 to 88 MHz comprising Channels 2 through 6, and 174 through 216 for Channels 7 to 13, with the FM band from 88 to 108 MHz. Within any given system a number of these channels may have been unusable due to over-the-air interference. With the new FCC regulations requiring a minimum of 20 channels on the system, and with many operators contemplating the use of up to 40 channels, the question of frequency allocations of the channels becomes particularly important.

At present, a number of alternate allocations are being considered by the Coordination Committee for Cable Communication Systems, Institute of Electrical and

Electronics Engineers. The sub-committee Working Allocation Plan for VHF cables is given in Table 4 (Powers, 1972). The specific frequency allocations as they are presently used on cable are given in Table 5.

Existing systems are primarily designed to provide for transmission of the twelve FCC channels plus FM over the coaxial cables. For these systems, the most economical approach for expanding to 21 channels is to use the nine broadband channels between 120 and 174 MHz. This is possible provided that the system amplifiers have sufficiently low second-order distortion. In this approach, each subscriber is furnished with a set-top converter. For new systems just being installed, a dual cable may be the most effective, since this allows later expansion to more than twenty channels and makes the addition of two-way service an incremental cost.

The most widely used and most widely understood specifications in the CATV trunking and distribution system are the system cross modulation and the signal-to-noise ratio. In general, the design specifications for service to the last customer drop allows 45-dB signal-to-noise ratio and -52 dB as the maximum level of cross modulation. Within these limitations, the noise and cross modulation must be allocated to the transportation, trunk, and distribution system. In systems without the transportation trunk, the

Table 4

Subcommittee Working Allocation Plan for VHF Cables

Freq.Band (MHz)	Allocation	Possible Uses
Below 54	EXPERIMENTAL	Television Subscriber Responses Telemetry Facsimile Control of Monitoring
54-72	TELEVISION	Cable Television, Class I and II
72-76	EXPERIMENTAL	Pilot Signals Control Signals
76-88	TELEVISION	Cable Television, Class I and II
88-108	AURAL BROADCAST	FM Broadcast Signals AM Broadcast Signals, Modulated to FM Local Origination, FM
108-120	EXPERIMENTAL	Subscriber Interrogation Signals Control Signals Pilot Signals
120-174	TELEVISION	Cable Television, Class I and II
174-216	TELEVISION	Cable Television, Class I and II
216-270	TELEVISION	Cable Television, Class I and II
270-300	EXPERIMENTAL	Cable Television, Class I, II, and III Facsimile
300-400	EXPERIMENTAL	Cable Television, Class Telemetry Subscriber Response Signals Monitoring Signals
Above 400	NOT ALLOCATED	

TABLE OF CATV CHANNELS VS. FREQUENCY IN MHz

CHANNEL NO.	BANDWIDTH	VIDEO CARRIER	COLOR CARRIER	AUDIO CARRIER	CHANNEL NO.	BANDWIDTH	VIDEO CARRIER	COLOR CARRIER	AUDIO CARRIER
T7	5.75-11.75	7.0	10.58	11.5	H	162.0-168.0	163.25	166.83	167.75
T8	11.75-17.75	13.0	16.58	17.5	I	168.0-174.0	169.25	172.83	173.75
T9	17.75-23.75	19.0	22.58	23.5	7	174.0-180.0	175.25	178.83	179.75
T10	23.75-29.75	25.0	28.58	29.5	8	180.0-186.0	181.25	184.83	185.75
T11	29.75-35.75	31.0	34.58	35.5	9	186-0-192.0	187.25	190.83	191.75
T12	35.75-41.75	37.0	40.58	41.5	10	192.0-198.0	193.25	196.83	197.75
T13	41.75-47.75	43.0	46.58	47.5	11	198.0-204.0	199.25	202.83	203.75
2	54.0-60.0	55.25	58.83	59.75	12	204.0-210.0	205.25	208.83	209.75
3	60.0-66.0	61.25	64.83	65.75	13	210.0-216.0	211.25	214.83	215.75
4	66.0-72.0	67.25	70.83	71.75	J	216.0-222.0	217.25	220.83	221.75
5	76.0-82.0	77.25	80.83	81.75	K	222.0-228.0	223.25	226.83	227.75
6	82.0-88.0	83.25	86.83	87.75	L	228.0-234.0	229.25	232.83	233.75
f-m	88.0-108.0	—	—	—	M	234.0-240.0	235.25	238.83	239.75
A	120.0-126.0	121.25	124.83	125.75	N	240.0-246.0	241.25	244.83	245.75
A	126.0-132.0	127.25	130.83	131.75	O	246.0-252.0	247.25	250.83	251.75
C	132.0-138.0	133.25	136.83	137.75	P	252.0-258.0	253.25	256.83	257.75
D	138.0-144.0	139.25	142.83	143.75	Q	258.0-264.0	259.25	262.83	263.75
E	144.0-150.0	145.25	148.83	149.75	R	264.0-270.0	265.25	268.83	269.75
F	150.0-156.0	151.25	154.83	155.75	S	271.0-277.0	272.25	275.83	276.75
G	156.0-162.0	157.25	160.83	161.75	T	277.0-283.0	278.25	281.83	282.75

Table 5. Table of CATV channel vs. frequency in MHz. (Courtesy of Magnavox).

allocation between subscriber trunk and distribution is nominally -57 dB and -58 dB, respectively, for cross modulation. When the transportation trunk is employed, the allocation to the distribution amplifier is unchanged, but the allocation of -57 dB to trunking has to include both transportation and subscriber trunk.

Figure 8 shows additional information that can be obtained from the cross-modulation signal-to-noise ratio diagram of Fig. 3. As in the computations for Fig. 3, the cross-modulation specification is 50 dBmV for -57 dB cross modulation. The amplifier noise figure is 9 dB. The nominal operating level is usually chosen halfway between the cross modulation and signal-to-noise limits. This means that the maximum voltage on the cable occurs at the output of the amplifier and is about 32 dBmV. The maximum number of amplifiers that can be cascaded in this example is 50 amplifiers (depending upon the particular amplifier specifications, this number varies from about 45 to 200 amplifiers).

As a practical matter, the amplifier cascade in a modern system rarely exceeds twenty amplifiers. This limitation is imposed primarily by the inability to maintain signal-level flatness in the installed system. Both Rheinfelder (1972) and Taylor (1966) point out the difficulty in measuring and adjusting the flatness of the system once it is installed.

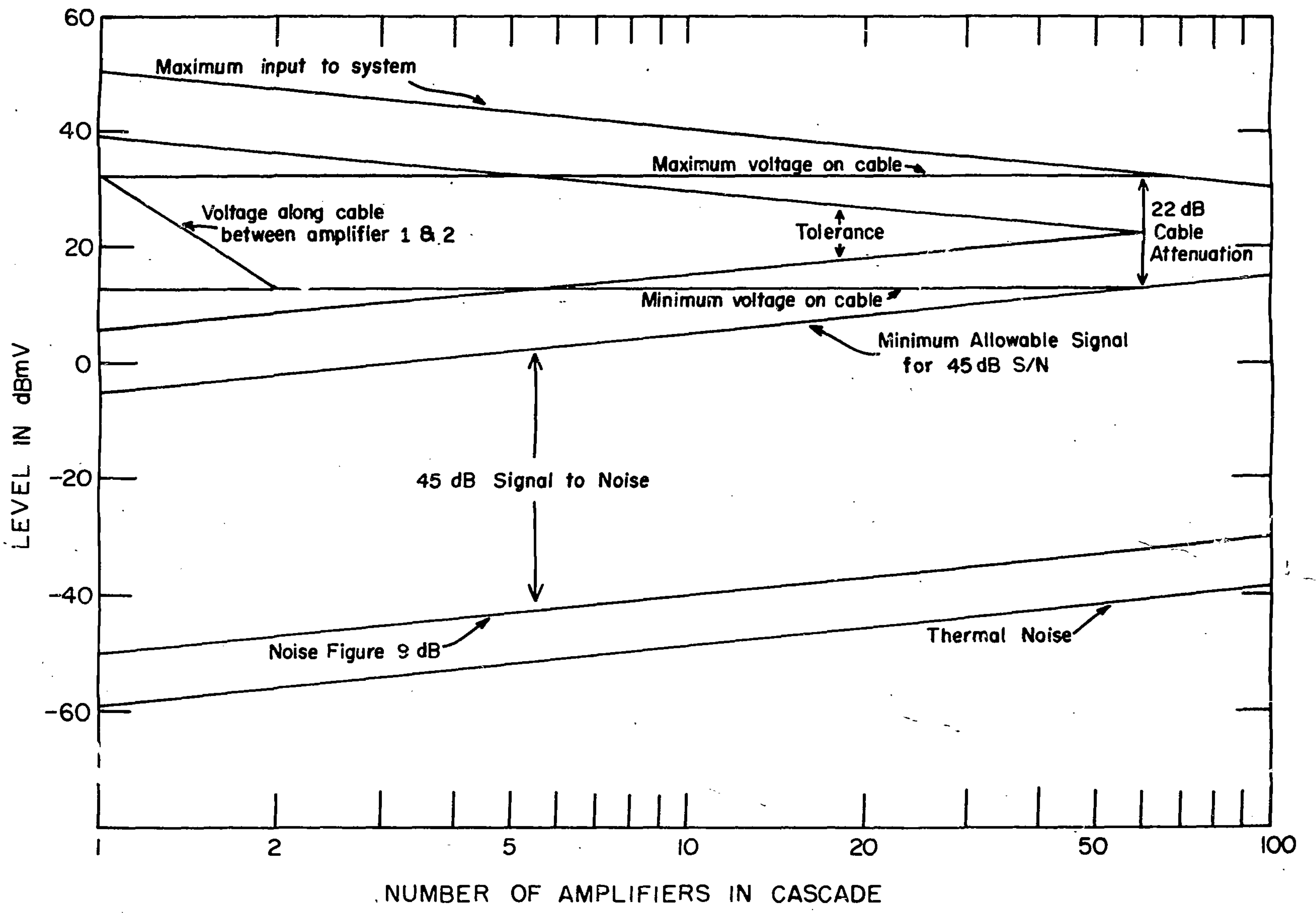


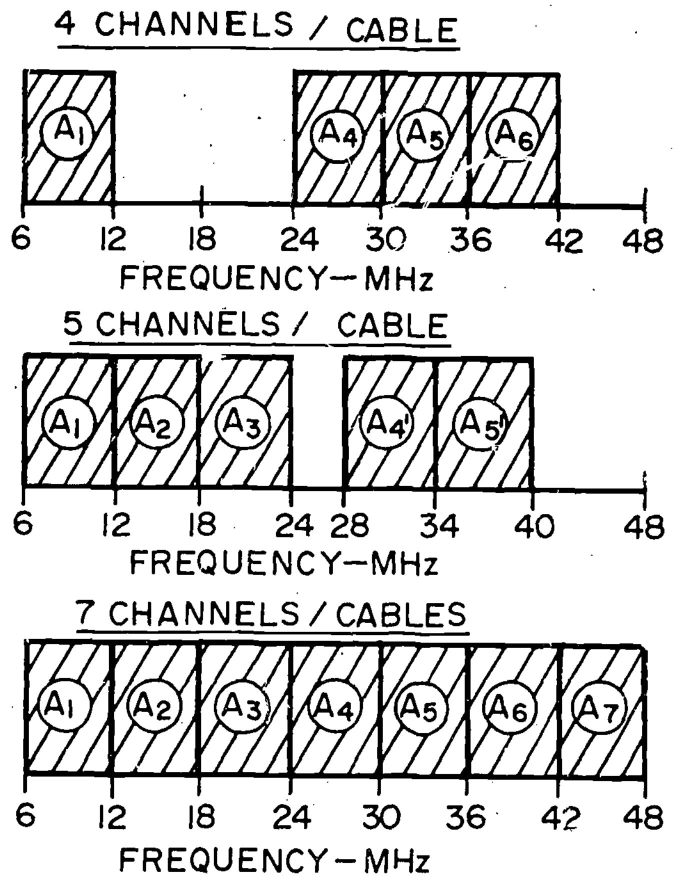
Figure 8. System Level versus System Length. Expanded Version of Figure 2 Illustrating Level Variation.

It appears that improved field testing measurements could lead to improved performance of these systems.

If in the design example twenty amplifiers are cascaded at 22 dB gain per amplifier with 1.06 dB/100 ft cable attenuation, then from the figure it is seen that for 0.750-in cable the maximum trunk distance is 7.9 miles. For 0.500-in cable, this is reduced to 5.4 miles. For large metropolitan areas, wuch distances are obviously too short to permit service to all possible subscribers, since many subhead-ends may be well beyond these distances. This is particularly true when it is considered that many good sized communities are really part of much larger metropolitan areas.

4.2 Sub-Band Trunks

Transportation of signals in the sub-band between 6 and 48 MHz is another approach which has been used successfully in long-distance trunking. This approach permits up to seven television channels per cable in various frequency arrangements, as shown in Fig. 9. The main advantage of this approach is the lower attenuation of the cable for frequencies below 50 MHz. As shown in Fig. 4, the attenuation of 0.750-ft cable is about 0.41 dB/100 ft, compared to about 1.07 dB/100 ft at 270 MHz. The length of the system with 1.07 dB/100 ft cable is 7.8 miles, while the length of the 0.41 dB/100 ft cable can be 20.3 miles, or

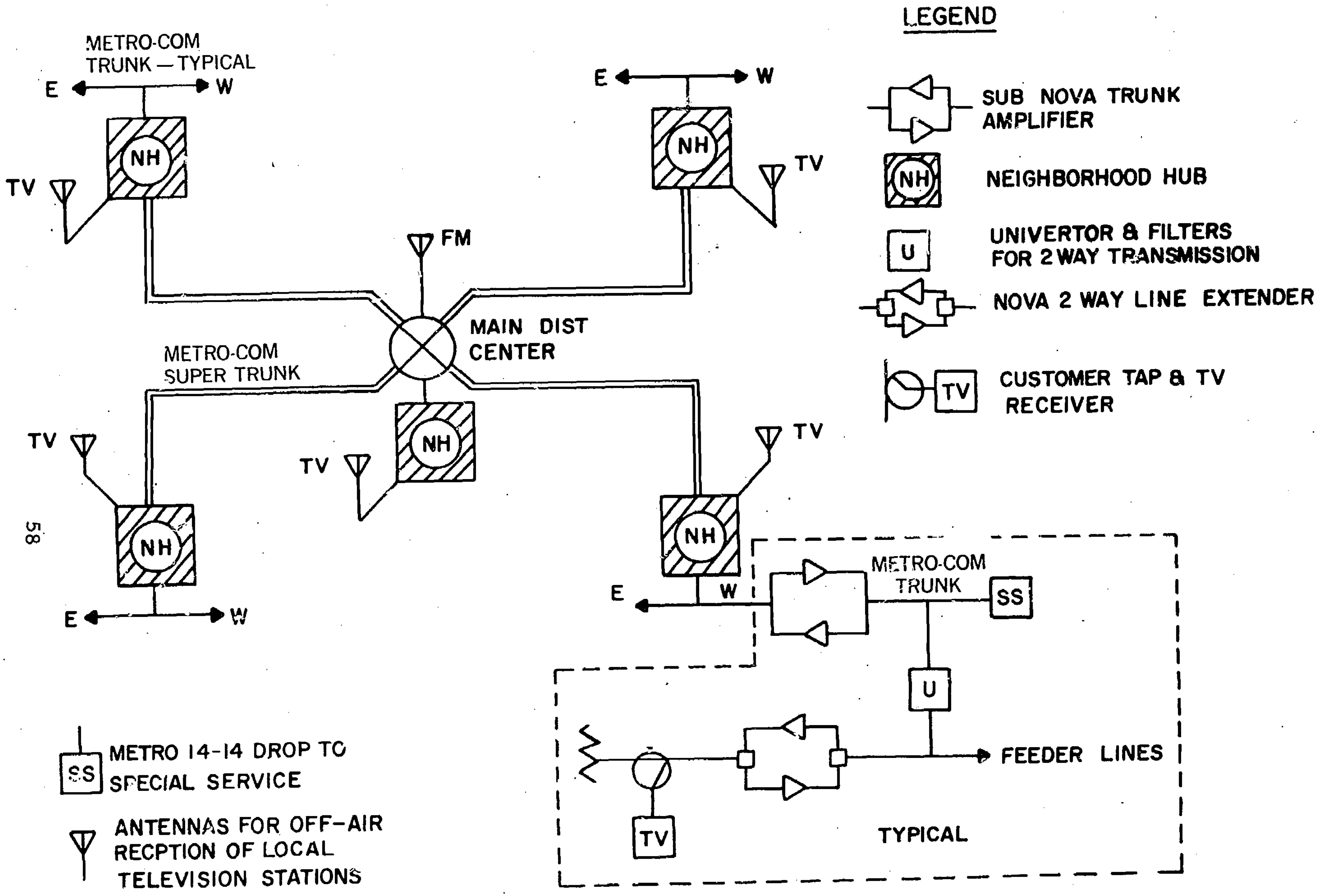


CHANNEL	BAND—MHz	CARRIER FREQUENCY—MHz	
		VISUAL	AURAL
A_1	6-12	7.25	11.75
A_2	12-18	13.25	17.75
A_3	18-24	19.25	23.75
A_4	24-30	25.25	29.75
A_4'	28-34	29.25	33.75
A_5	30-36	31.25	35.75
A_5'	34-40	35.25	39.75
A_6	36-42	37.25	41.75
A_7	42-48	43.25	47.75

Figure 9 Transportation system -- spectrum utilization. (Metro-Com illustrations courtesy of Ameco, Inc.)

alternatively for the 7.8-mile system, only 8 amplifiers are required to built the trunk. Actually, even fewer amplifiers are required because the channel loading per amplifier is reduced, which increases the maximum input signal. The noise figure is somewhat smaller due to reduced bandwidth, and undoubtedly the problems of flatness are reduced due to the narrow bandwidth. Thus, the number of amplifiers which can be cascaded is increased. Indeed, the manufacturer of such systems claims about 7900 ft between amplifiers and an amplifier advantage of 4 to 1 per cable over broadband trunks. In reality, of course, the advantage is not as large, since the number of channels carried per cable is only 7, compared to 21 in the conventional approach. Thus, the real advantage is open to argument. Since the argument is basically economic for cable trunks shorter than 0.5 to 7 miles, it would appear that a prudent system approach would be required to properly evaluate the best technique. For trunks longer than 7 miles, the problem is one of determining the advantage of this approach over that of microwave transmission.

An obvious disadvantage of this technique is the requirement to combine, at some point in the system, the signals from many cables onto one cable for distribution to the subscriber. A typical system is shown in Fig. 10, with the frequency allocation shown in Fig. 11. In the system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NOVA 2 WAY LINE EXTENDER
TV
CUSTOMER TAP & TV RECEIVER
METRO-COM TRUNK — TYPICAL
E
W
TV
FM
MAIN DIST CENTER
METRO-COM SUPER TRUNK
METRO-COM TRUNK
SS
FEEDER LINES
TYPICAL
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METRO 14-14 DROP TO SPECIAL SERVICE
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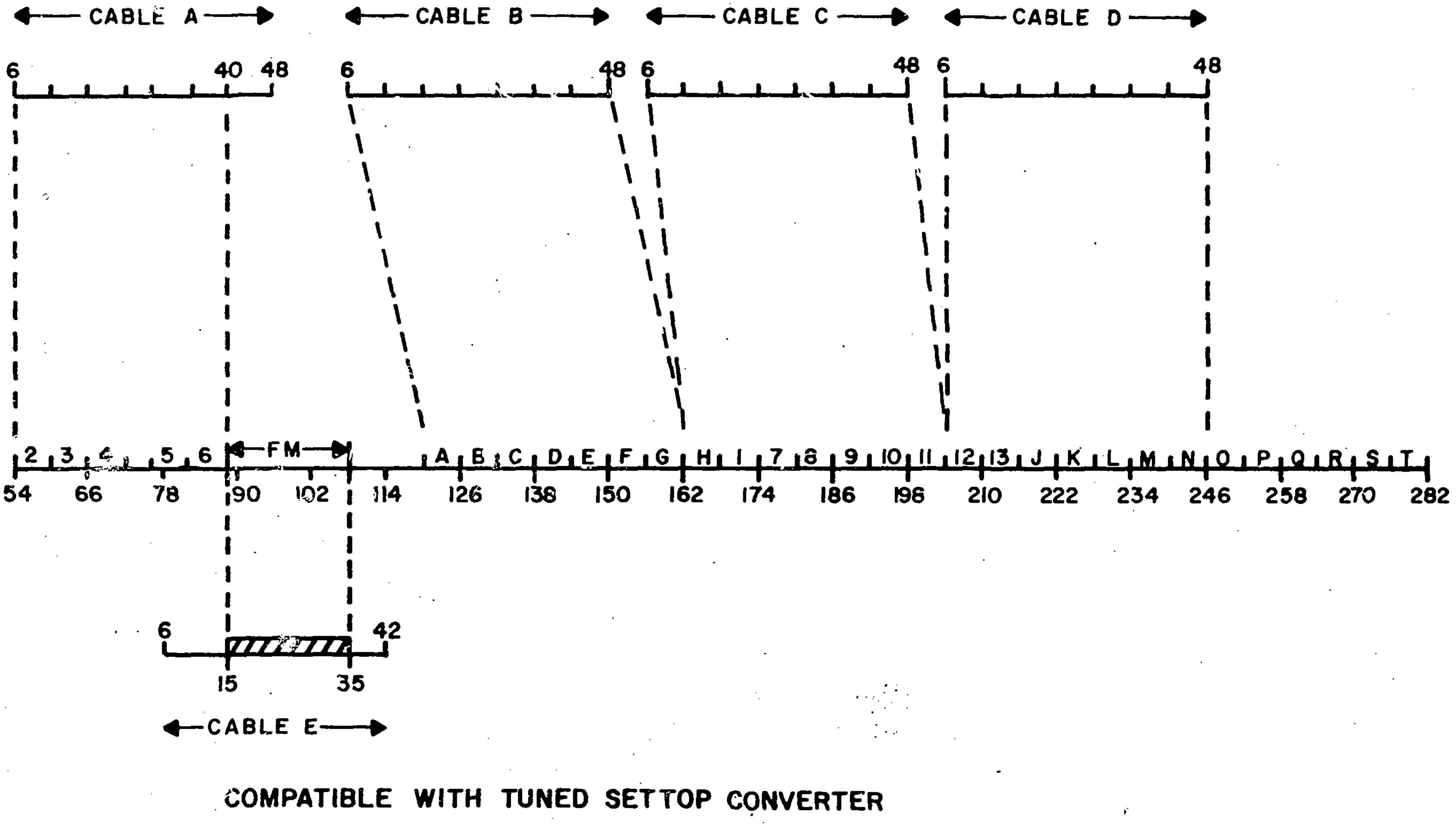

Figure 11. Frequency translation -- Univertor, Model III
(Metro-Com illustrations courtesy of Ameco, Inc.)

shown, the signal combiner is located beyond the hub or subhead-end. It may be more advantageous to use a mixed system with subchannel trunking between head-ends and conventional trunk and distribution beyond. Obviously, these are factors to be considered in the specific design.

Typical problems in using the subchannel systems are similar to those encountered in a conventional system. The use of more connectors and amplifiers makes the maintenance of individual components more expensive; however, the addition of a spare cable at relatively small additional cost could provide a standby which could be switched into the system while other channels are being repaired or aligned.

4.3 Microwave Links

Within the past two years, multichannel CARS band microwave systems have begun to emerge as a new alternative to cable for super-trunking applications. The use of conventional single-channel microwave has indeed been the very basis for the success of CATV, but until the development of the multichannel systems, the use of microwaves for trunking within the hub center has been of only limited usefulness.

In concept the broadband microwave links are quite simple. The collection of TV channels is translated by some form of modulation into the microwave CARS band between

12.700 and 12.950 GHz and is transmitted over the path to an appropriate receiver located at a sub-head-end. The signals are received, reconverted to appropriate VHF signals, and passed on to the remainder of the distribution system for delivery to the subscriber.

Conventional single-channel FM microwave links are found to be unsuitable for three important reasons. First, the CARS band allocation is only 250 MHz wide; thus, with conventional FM using 25 MHz or 15 MHz, depending upon the particular system, the band can support only between 10 and 15 channels over one path. Second, each channel requires conversion from VHF to baseband before transmission and reconversion to VHF upon reception. This adds expense to the system and contributes to the signal deterioration. Finally, the usual approach to these systems is a single antenna per channel at the transmitter and receiver terminals; and although frequency division multiplexing using passive microwave components to give multiple channels per antenna is entirely feasible, this has not been generally done.

Recently, two new types of multiple-channel or broadband microwave systems have been introduced. The first of these types is amplitude-modulated frequency-division multiplexed (Sonnenschein, 1972). In this approach, the VHF channels are up-converted directly to an appropriate CARS band channel, transmitted over the path, and then down-converted to the same VHF channel for insertion into the cable trunk. Since the signals are up-converted directly, the modulation format of the VHF channel is unchanged and an individual channel still occupies only 6 MHz; thus, the 250 MHz available will support 40 channels. In this approach, the up-conversion is accomplished on a per-channel basis with frequency division multiplexing done by using passive components to eliminate the generation of cross-modulation distortion in the transmitter. (One manufacturer uses an output traveling wave tube amplifier to boost transmitted power.) In the receiver where low signal levels exist, block-down conversion is possible and all channels are simultaneously down-converted to the correct VHF frequency. Figure 12 shows the VHF-to-CARS band frequency adopted for at least one system. A historical review of the development of single sideband for microwave systems is given by Ivanek (1972).

The other approach to local distribution by microwave is called frequency-division multiple-frequency modulation. In this approach, eighteen TV channels are down-converted to the frequency region between 5 and 114 MHz. This baseband signal frequency modulates a low microwave frequency subcarrier which is up-converted to CARS band and amplified by a TWT amplifier for transmission. The claimed advantage

FREQUENCY LOCATIONS OF TV CHANNELS

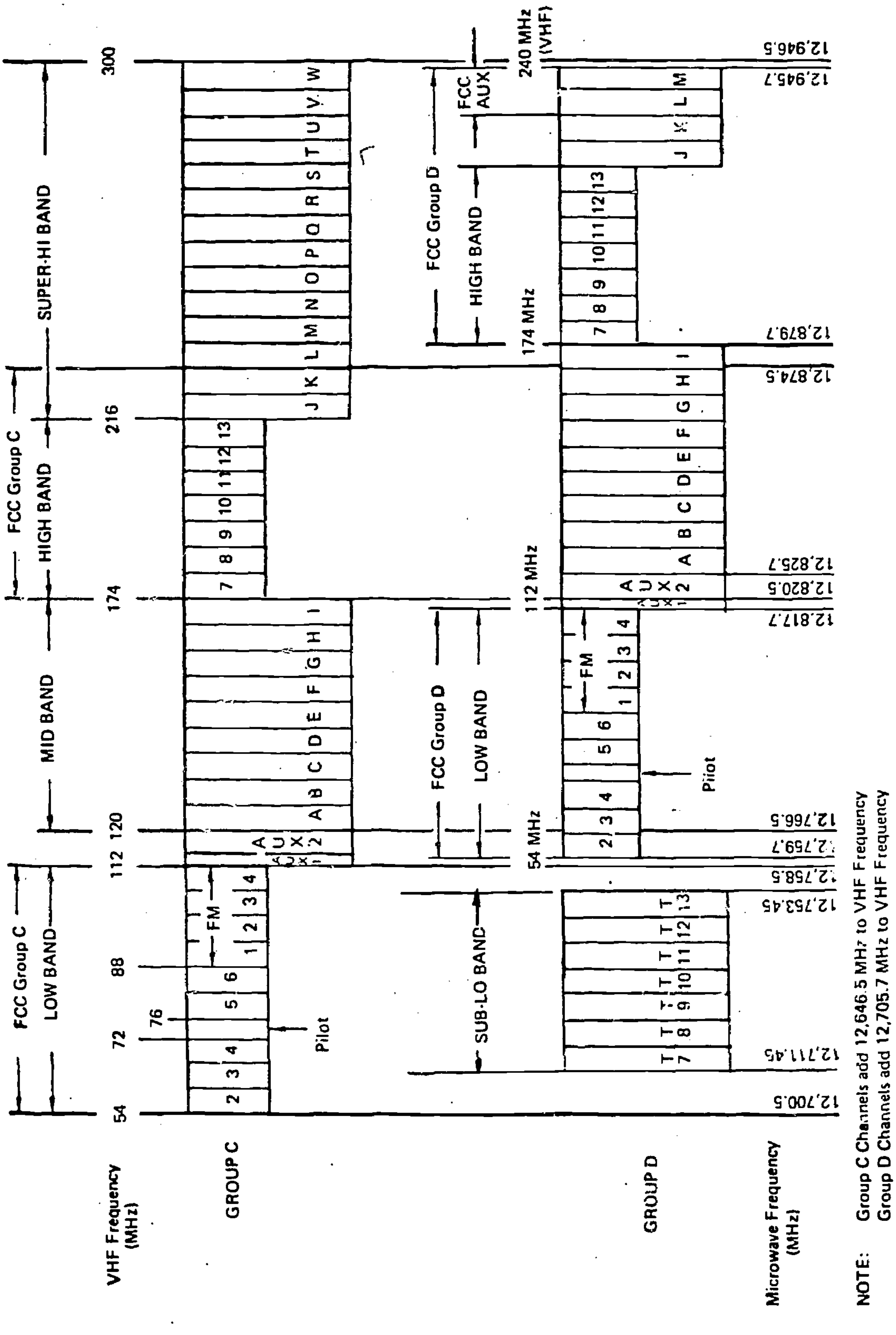

Figure 12. Frequency Locations of TV Channels. (Courtesy of Theta-Com of California.)

of this approach is the ability to transmit extremely high powers from the TWT without excessive cross-modulation distortion. A disadvantage of this approach appears to be a limitation on the possible number of channels within the 250-MHz limitation of the CARS band. Non-flat fading may also be a problem, since the signals for a particular channel occupy more bandwidth than with an amplitude-modulated system.

At present, there is considerable controversy among the manufacturers of this equipment about these fundamental limitations on performance. As a practical matter, however, the installation of systems will most likely be determined by a demonstration of working systems having acceptable quality, on-time installations, and equipment having adequate reliability.

It is obvious that the advantage of microwave over cable trunking can be determined only on the basis of performance and price. The distance performance advantage of using a microwave sytem is readily shown in Fig. 13. In this figure, it is assumed that the cable amplifiers have a cross-modulation performance of -93 dB at 32 dBmV (50 dBmV at -57 dB X mod). Given that the microwave link can achieve a cross-mod performance of -85 dB, then the combined cross modulation of the microwave link and one amplifier is -82 dB. The combination of the twenty-amplifier cascade and the

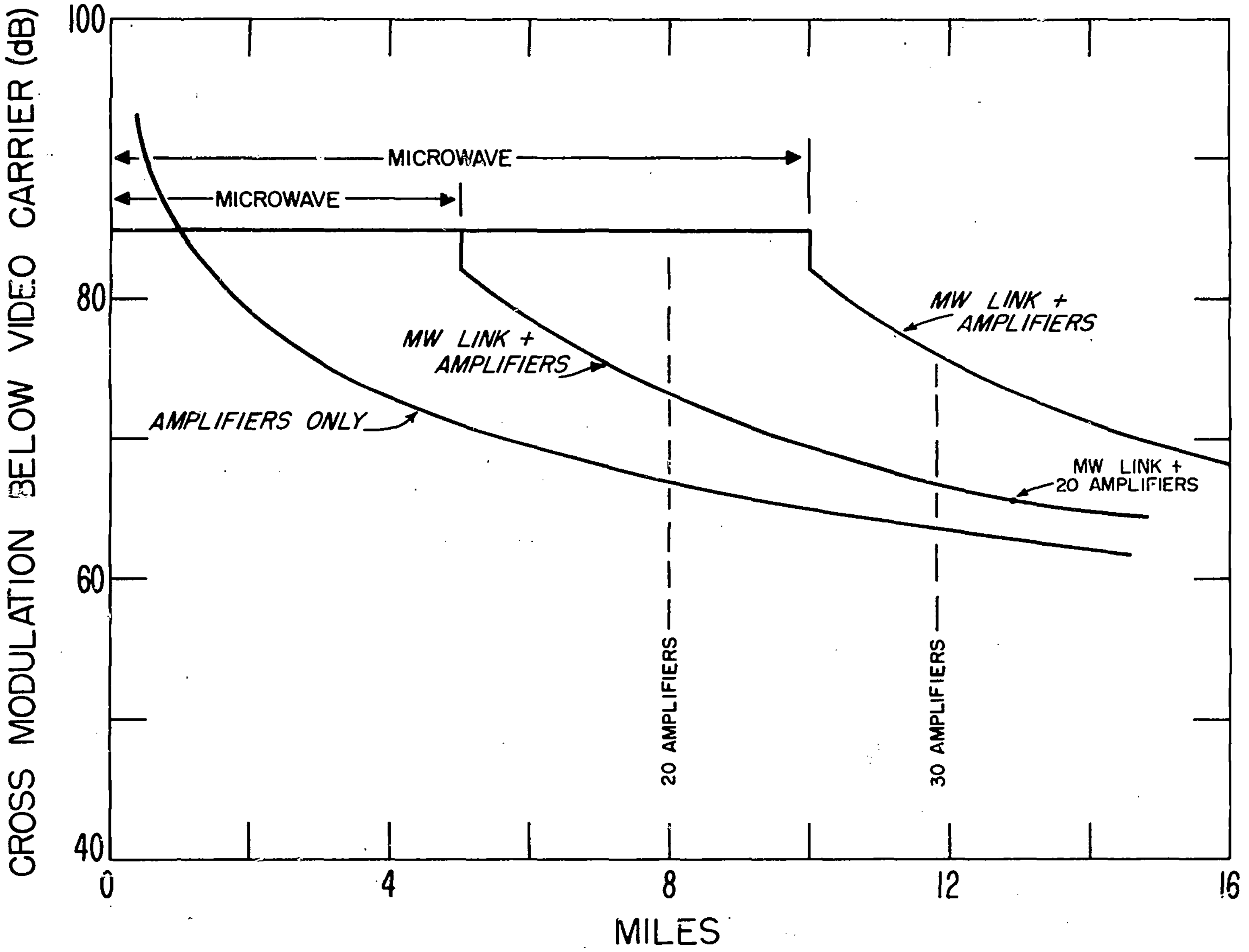

Figure 13. Crossmodulation versus System Length for Cable and Microwave Systems.

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microwave link is only 1 dB worse than the 20-amplifier cascade alone. If the cross modulation of the amplifier cascade is as bad as -57 dB, the degradation is only about 1/2 dB. The signal-to-noise contribution to a long cascade (10 amplifiers) can also be shown to be only about 1/2 dB. In general terms, this means that the microwave link can be built such that very little signal degradation between headends is possible.

Potentially one of the most serious problems facing the users of microwave links is outage due to signal attenuation at 13 GHz caused by rainfall along the propagation path. The problem facing the designer is to develop a system with the least outage for a particular area. The problem for the user is to decide if the number of hours of outage that will be experienced each year can be tolerated or if an alternate method of delivery must be chosen.

The probability that an outage will occur for a particular link is just the probability that the rain attenuation for a particular path exceeds the threshold of permissible fading or fade margin for this link. Various models for the prediction of outages based on rain statistics have been proposed, but the critical problem is the prediction of surface rainfall (Medhurst, 1965; Oguchi, 1964; Dutton, 1967; Zufferey, 1970; Crane, 1971). The authors of this report feel that the prediction model for rainfall statistics developed by ITS (Rice, 1972) comes as close to reality as is possible with presently-available data. The attenuation rate of rainfall is not a simple function of the rainfall rate. In addition, it is also a function of the horizontal rainfall distribution as well as the temperature of the rain. Consequently, any models of outage due to rain are subject to some uncertainty.

The attenuation γ (dB/km) of the rain is given by (Ryde, 1946)

$$\gamma = \alpha R^{\beta} \quad (\mathrm{dB/km}) ,$$

where R is the rainfall rate (mm/hr) and α and β are parameters which are a function of frequency, temperature, and rainfall rate. For a frequency of 13 GHz, the dependence on rainfall rate is relatively weak and $\beta \cong 1.22$, while α is about 1.82×10^{-2}. The dependence of γ on temperature is about 20% from near 1 mm/hr to 150 mm/hr from 0°C to 20° C. The value shown here results in a slightly pessimistic estimate of outage. Some discussion of the limitations of the above expression and its extension to higher frequencies is available (Medhurst, 1965; Crane, 1966).

To determine the probability of an outage due to rainfall, it is necessary to find the probability that the rainfall rate exceeds a particular value, i.e., the probability distribution function of the rainfall rate. A prediction model for this distribution function is available (Rice, 1972). The location-dependent parameters are the average total rainfall and the maximum rate to be expected in two years. Five different regions have been used to specify these parameters on a world-wide basis (CCIR, 1972), but information on eleven different regions in the continental United States and Southern Canada is also available (Hull et al., 1970).

Using the model, the total expected outage as a function of fade margin for 10-mile CARS band paths in several U. S. cities is given in Figure 14. Further, Figs. 15, 16, and 17 give the same outage time versus fade margin information for three different U. S. cities Denver, Chicago, and New Orleans.

The rainfall outage problem has been studied for many years and there appears to be only one widely accepted solution. The experience of the telephone system shows that route diversity is a very effective solution. However, due to the expense required, route diversity does not appear as a practical solution for CATV systems.

Fading on line-of-sight paths is of two types: power fading and multipath fading. Power fading includes effects of beam bending and attenuation due to precipitation, which has already been discussed. Multipath fading includes phase

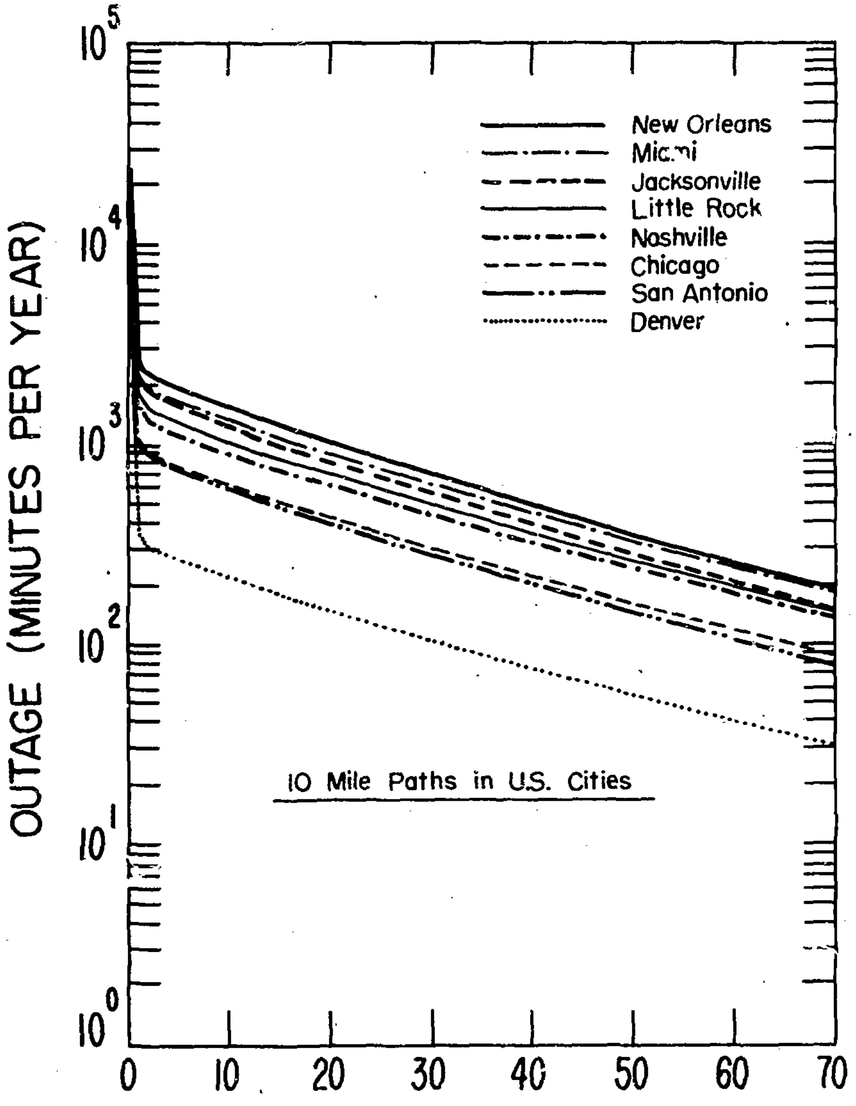


Figure14. Outage versus Fade Margin for 10 mile paths in several U.S. Cities

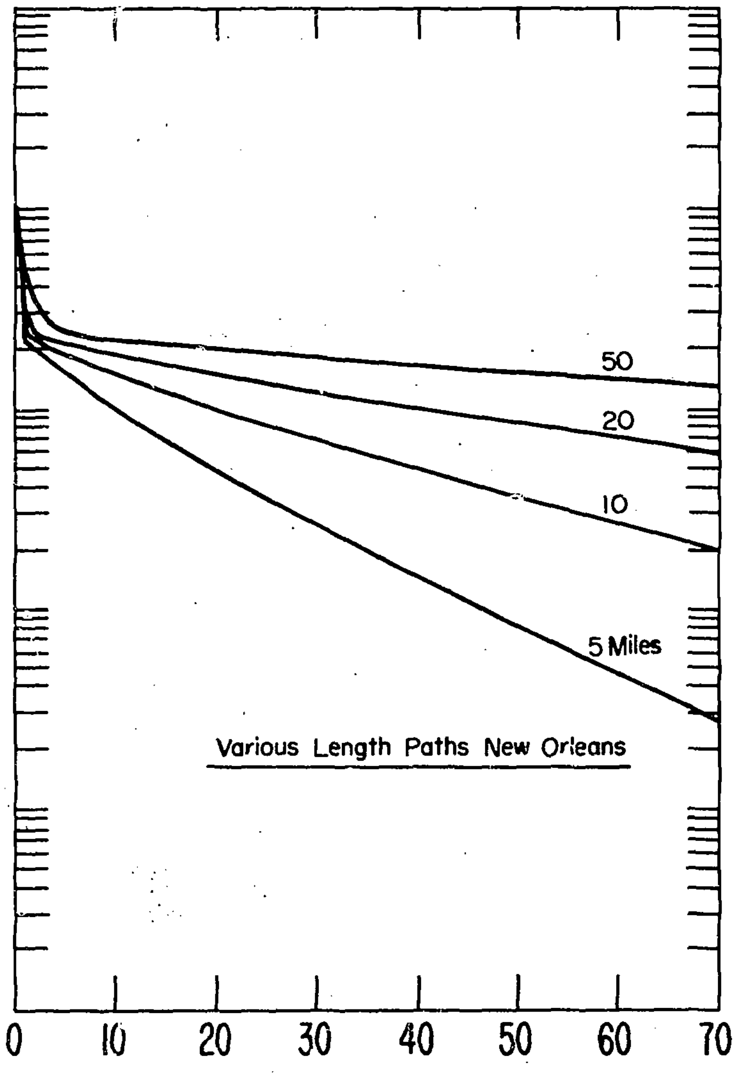
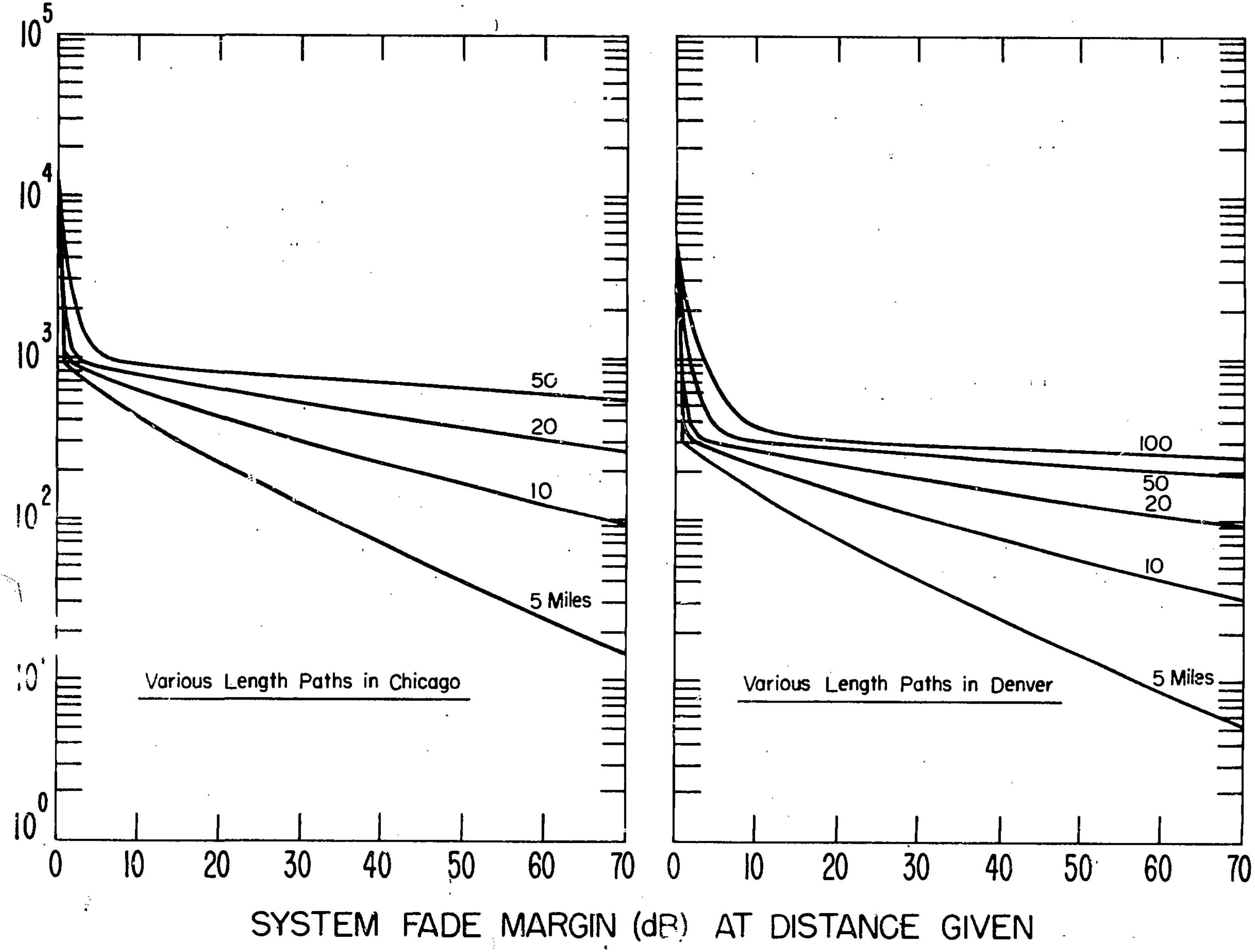


Figure 15. Outage versus Fade Margin for various path lengths in New Orleans.



Figures 16 & 17. Outage versus Fade Margin for Various Path Lengths in Chicago and Denver.

interference effects from ground-reflected and atmospheric paths.

Power fading results when the energy received by the receiving antenna is less than normal because of one of two effects. The signal can be highly attenuated by rain, as was discussed above, or the signal can be diverted away from the receiving antenna by atmospheric ducts and layering. The best defense against this is site selection, positioning the antennas so as to avoid the effects of the atmospheric layering. However, this may be only slightly adjustable in a CATV system, since the receiver must be relatively near the subscribers.

Multipath fading differs from power fading in that the transmitted signal reaches the receiver by two or more distinct paths and the resultant received signal undergoes constructive and destructive interference. The multipath components can be from terrain reflections or from various meteorological effects (Magnuski, 1956; Nicolis, 1966; Misme, 1958; Dougherty, 1968). The important feature of multipath fading is that it is frequency and spatially selective, as opposed to power or flat fading. The frequency-selective character of multipath means that in a frequency-multiplexed system, such as a CARS band system, some of the channels can be, at times, completely unusable. A feature of multipath fading is that the received signal power can be greater than the free-space signal due to constructive interference.

There are two techniques to protect against multipath fading. Both space diversity and frequency diversity provide excellent methods for guarding against deep fades.

Ducts and layers cause power fades up to 20 dB or more which may persist for hours or days, but tend to be less frequent during daylight hours. This mechanism, which may sometimes be due to several layers, is the probable source of many "space-wave fadeouts" (Bean, 1954; Barsis and Johnson, 1962).

For designing radio relay systems conforming to CCIR Recommendations, it is necessary to protect against the probability of deep fades for very small percentages of the time, e.g., about .0002%.

Design of diversity separations as a function of frequency, antenna height, path length, and expectation of atmospheric behavior is given by Dougherty (1968) for maritime paths. A simple, generally effective space diversity design procedure is given by CCIR Study Group IX Doc. 9/35 (1972) based on Vigant's (1968) work. A recommended vertical spacing, center-to-center, is

$$\Delta h = 0.3\sqrt{\lambda d} \text{ ,}$$

where the path length d, wavelength λ , and spacing h are all in the same units. Almost any spacing will provide some improvement.

Obviously the FCC regulations preclude the use of frequency diversity of CARS band for delivery of CATV signals. Indeed, the economics of CATV may preclude the use of space diversity as well. An optimum approach has not been devised as yet, but certainly careful site surveys which include evaluation of local meteorological phenomena can do much to enhance system performance.

5 DELIVERY OF SIGNALS TO SUBSCRIBER

5.1 One-Way Systems

When considering systems for signal delivery to the home, it is convenient to rank the systems in order of increasing capability and complexity. There are perhaps several ways of doing this, and the ordering presented here includes most proposed and operating systems.

The simplest system is the conventional CATV delivery system with one-way capability, a single trunk and a single feeder per subscriber. A typical arrangement is shown in Fig. 18, and advantages, disadvantages, and required equipment are also given.

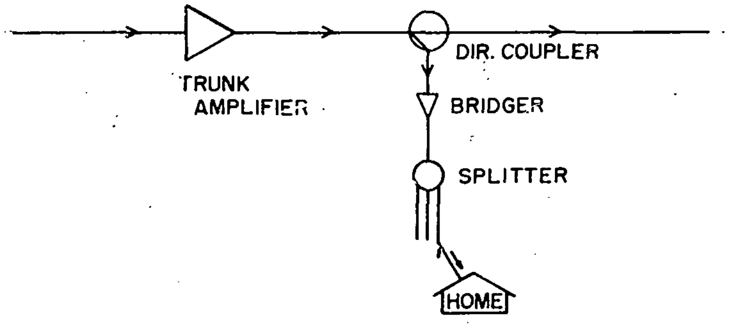


Figure 18. One-way, Single-Trunk, Single-Feeder (OSS) System.

Advantages:

(1) Can result in minimum cable length system to cover a specific area.

(2) Trunk cascaded elements are amplifiers and directional couplers.

Disadvantages:

(1) Provide only minimum capability.

Equipment:

(1) Trunk amplifier:
Bandwidth: 250 MHz, 2500-ft spacing
Gain: 16 dB at 57 MHz; 35 dB at 250 MHz
VSWR: <1.35.

(2) Coax Cable: 1/2-in diameter
Attenuation: 15.8 dB at 57 MHz; 35 dB at 250 MHz

(3) Directional Couplers: to tap trunk line.

(4) Power splitters: to divide power to users.

(5) Home Terminal: common TV set.

The next system in the heirarchy has one-way capability, dual (or multiple) trunks, and one feeder per subscriber. Most larger systems are of this type, where the different trunks cover different geographical areas. This is shown in

Fig. 19, along with advantages, disadvantages, and equipment.

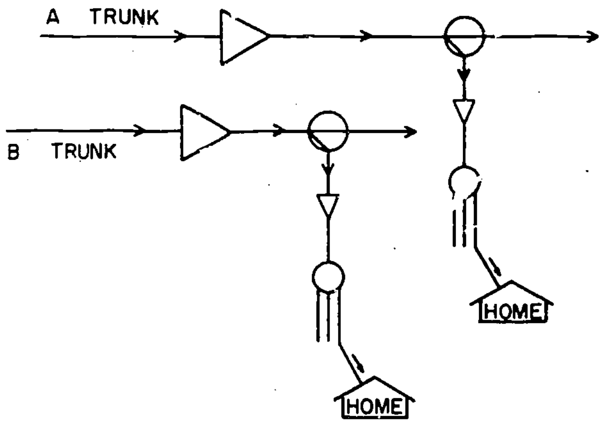


Figure 19. One-Way, Dual-Trunk, Single-Feeder (ODS) System.

Advantages:

(1) Program material can be directed simultaneously at different audiences.

(2) Possible to have fewer cascaded trunk elements.

Disadvantages:

(1) Has no more capacity than CSS system.

(2) If the different audiences are not separated, the trunk length can be doubled.

Equipment:

(1) Same equipment as OSS system, except trunk length may be longer.

If more capacity per individual subscriber is needed but no two-way capability is required, a one-way, dual-trunk, dual-feeder system can be used. This system is shown in Fig. 20 with advantages, disadvantages, and equipment.

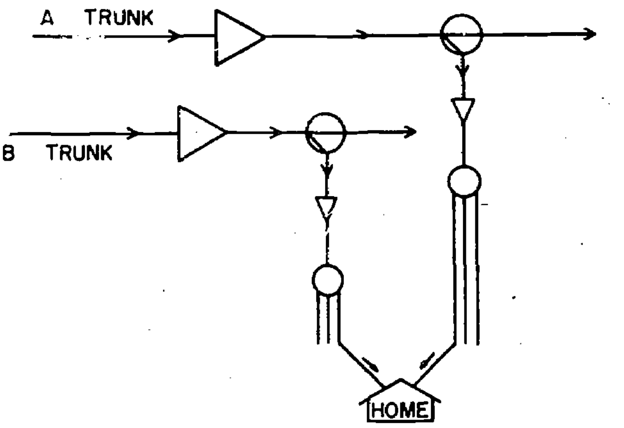


Figure 20. One-Way, Dual-Trunk, Dual-Feeder (ODS) System.

Advantages:

(1) Capacity to home is doubled over OSS.

(2) Can be changed to a two-way system relatively easily.

Disadvantages:

(1) Length of cable is doubled over that for OSS system.

(2) Home terminal requires an A-B switch.

Equipment:

(1) Same equipment as OSS system plus an A-B switch at the home terminal.

5.2 Two-Way Systems

Most of the new services involve two-way capability and, since signals can flow either way in a coaxial cable, it has been proposed that existing systems can be changed over to two-way systems by simply using two-way amplifiers. This is an oversimplification and is the reason that some large system operators are going to the dual-trunk concept to obtain two-way capability. However, the two-way, single-trunk concept is used and perhaps will continue to be used. The main component needed is the high-low split filter which splits the high frequencies into the downstream amplifier and blocks them in the upstream direction. The disadvantage of this technique is that the signals suffer distortion in the frequency region around the transition from high to low frequencies. A typical arrangement for a two-way, single-trunk, single-feeder system is shown in Fig. 21, along with advantages, disadvantages, and required equipment.

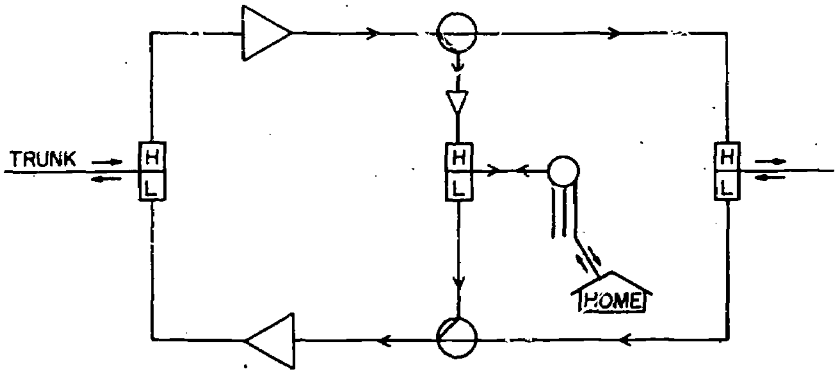


Figure 21. Two-Way, Single-Trunk, Single Feeder (TSS) System.

Advantages:

(1) Same cable length as OSS, but has a two-way capability.

Disadvantages:

(1) High-low split filters are cascaded in the main trunk.

(2) Entire bandwidth of trunk cannot be used due to the filter cross-over region.

Equipment:

(1) Same cable as OSS, but for each repeater there are (in addition to OSS repeater) three high-low filters and an additional amplifier.

Return amplifier need not have same bandwidth as trunk amplifier.

(2) Home terminal must have message-sending capability.

To avoid cascading filters on the main trunk, a two-way, dual-trunk, single-feeder system has been proposed. However, at this time, it does not appear that any of these systems are in operation. One possible realization is shown in Fig. 22, along with advantages, disadvantages, and required equipment.

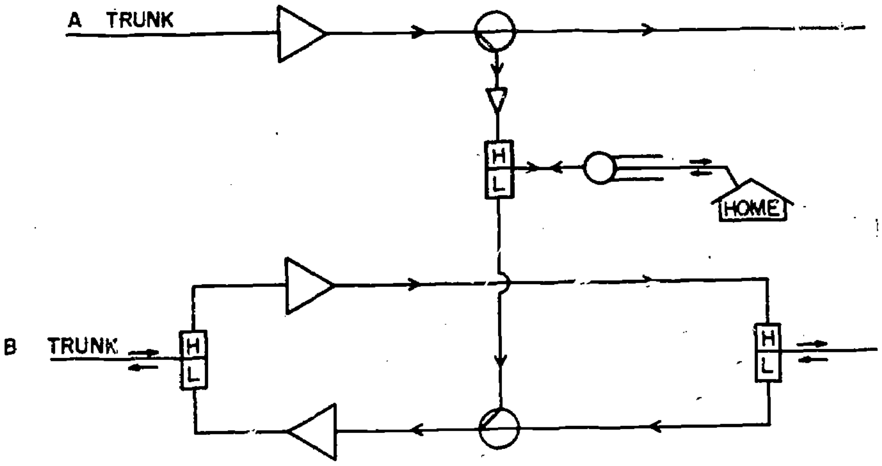


Figure 22. Two-Way,Dual-Trunk, Single-Feeder (TDS) System.

Advantages:

(1) There are no cross-over filters cascaded on the main trunk.

(2) No more cross-over filters per repeater than TSS system.

Disadvantages:

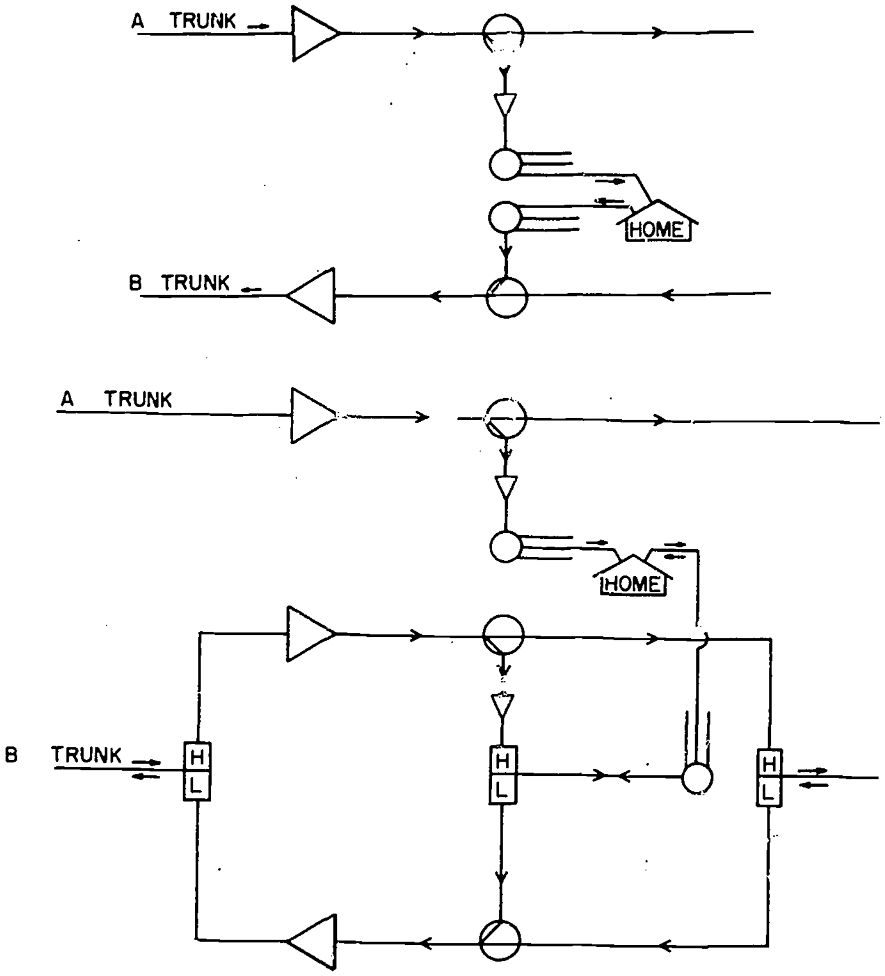
(1) Entire capacity of both cables cannot be utilized because of cross-over filter.

(2) Downstream capacity of B channel is not available to two-way users of the A trunk.

Equipment:

(1) In addition to TSS equipment, a second trunk line and one additional trunk amplifier per repeater.

The most vers(a)tile distribution system is the two-way, dual-trunk, dual-feeder system shown in Figs. 23(a) and (b). The simplest method is to use one trunk for the upstream and the other trunk for the downstream, as shown in (a). However, if more downstream capability is needed, the system shown in (b) can be used. It is likely that the two-way, dual-trunk, dual-feeder system is the one that will find the most used in the future and, in fact, it may be the only one that will meet the demands of modern society.



Figures 23 (a) and (b). Two-Way, Dual-Trunk, Dual-Feeder (TDD) Systems.

Advantages:

(1) There are no cross-over filters in the A trunk system, so the entire capacity of the cable can be used.

(2) No more cross-over filters per repeater than TSS or TDS.

(3) Since TDD is an OSS in parallel with TSS, either OSS or TSS can easily be converted to TDD.

Disadvantages:

(1) Entire capacity of B trunk cannot be used because of cross-over filters.

Equipment:

(1) Only one power splitter and one directional coupler per repeater and additional feeder lines needed to change TDS to TDD.

5.3 Broadband Communications in Rural Areas

Urban CATV systems offer a tremendous number and variety of present and potential services coupled with viable system economics. Population density is, however, a highly important parameter in the determination of economic feasibility. It is this consideration which inhibits the introduction of broadband services to rural areas.

It seems clear that a typical system with bandwidth of 5-260 MHz would be far too expensive for rural applications; this conclusion may be drawn even from a superficial consideration of trunk amplifier density for the wideband system. Generally, about 2.5 trunk amplifiers per mile are used. Assuming that only three or four subscribers may be served per mile of trunk line, it becomes apparent that such a system in rural locales would be very expensive. When one also studies the problem and equipment involved in transporting the signal from the trunk to the subscriber, the doubts can only be reinforced.

If a reduced bandwidth is considered, the problem is somewhat lessened. For example, one manufacturer uses a multiple cable concept which allows only two video channels per cable--the system passband then extends only to 40 MHz. Cable losses are then relatively low, e.g., half-inch cable at 40 MHz has an attenuation of around 27 dB per mile. This manufacturer, in fact, uses trunk amplifiers at 30-dB intervals, or a 0.9 amplifier per mile density. The two sub-split channels are converted to a preselected split-band channel via a set-top converter at the subscriber location. The converter, besides performing the required frequency conversions, also provides the switching among the various system cables. A modified version of such a system might provide broadband services to rural areas; a rudimentary switched system might also be a possibility.

More realistically, a rural telephone system developed by the Rural Electrification Administration (Buster, 1969) might be considered. This is a carrier system using coaxial transmission lines, and has been successfully tested and applied by some independent telephone companies which have borrowed capital from the REA. The development has allowed quality service to be provided to areas which previously had poor service or no service whatsoever.

These "station carrier" systems, as they are called by the REA, are presently designed for a 136-kHz bandwidth, far too little for even a single television channel. Even if television transmission cannot be included, good quality voice channels allow for certain low data-rate digital services which can certainly be transmitted within a 3 kHz bandwidth. It is felt, however, that the presence of such systems for voice communications could form the foundation for broadband services which might be offered as the technology advances for low-cost communications equipment. For example, the development of relatively inexpensive PCM devices could spur the extension of broadband communications into rural regions.

In any case, it seems apparent that the inclusion of voice communications in any rural wideband system is inevitable; the 3-kHz bandwidth required per subscriber is nearly negligible.

Perhaps the most striking facet of the rural communications problem is the dearth of information relating to any aspect of the question. Certainly private concerns are reluctant to launch studies of the problem because prospects for a return on their investment seem remote at present.

It remains that a study effort of some degree is in order; such an investigation should seek both economic and technical information, especially with regard to the possibility of initiating broadband service in the near future. The study should include comprehensive information on available equipment which might provide service. It especially should indicate developments that must be made to enable the institution of high-quality service. Simultaneously, plant costs and operating costs should be studied with the goal of predicting subscription rates. It is likely that rural populations would require different services than those supplied to urban areas; the nature of these requirements should be studied in some detail.

6 APPLICATION OF ADVANCED TECHNIQUES

6.1 Digital Transmission for CATV Signals

Digital transmission usually has been thought of as a technique to be used where high performance is required and cost is not a prime consideration, as in the space program. However, in recent years there have been a number of developments which have lowered the cost of digital transmission, and everything points to this trend continuing into the future. One important thing is that integrated circuits have lowered the cost of equipment considerably. Another important development is that the military has decided to convert all of their communications to digital transmission within ten years, which should result in even lower costs. The Bell System plans that their major transmission between population centers in the 1980's will be by buried waveguide transmitting digital signals in excess of 500 M bits/sec.

The main advantage of digital transmission is that generally the digital system can operate at a lower channel signal-to-noise ratio with less dynamic range and still deliver the same performance as a conventional system, which in a CATV system means that smaller and cheaper cable or less expensive amplifiers can be used. The second advantage is that digital signals are more amenable to cascaded transmission systems, as in CATV. The major disadvantage of digital transmission is that usually more bandwidth is needed for the same information. In this section, two digital techniques are discussed and twenty-two different digital systems are compared with TV video analog transmission and commercial FM.

In digital transmission, the signal is quantized into any number of levels before transmission, and the signal transmitted indicates which quantization level the signal is in. In the absence of errors, the quantized signal is reproduced exactly at the receiver and, if the number of quantization levels is large and the signal was sampled fast enough, an excellent replica of the original signal is available at the receiver. The requirement on the sampling rate is that the signal must be sampled at a rate greater than twice the highest frequency component in the signal. This is the well-known sampling theorem.

The requirement on the number of quantization levels is determined by how faithfully the signal must be reproduced at the receiver. The difference between the desired signal and the quantized signal is called the quantization noise or quantization error, and the ratio of signal power over the mean square value of the quantization error is then called the signal-to-quantization-noise ratio. It is clear that the signal-to-quantization-noise ratio is made large by making the number of levels large, but this means that more information must be sent for each sample.

Another type of noise at the output of the receiver is that due to errors introduced when the receiver makes an incorrect decision as to which level the signal was actually in. These detection errors produce an error at the output of the receiver and the signal power over the mean square value of this error is called the signal-to-detection-noise ratio. The signal-to-detection-noise ratio can be made large by increasing the transmitted signal power.

The two types of noise, quantizing noise and detection noise, will have completely different effects on the visual display of a TV set. The quantizing noise will always be present and tend to appear as contours on the picture. Detection noise will appear as occasional dots or very small areas incorrectly shaded, but will not be present on every picture. The difference between the two types of noise is that quantizing noise is a low-level noise spread throughout the picture while detection noise is a higher-level noise which appears as occasional, isolated dots. It is a matter of subjective judgment on the viewer's part as to which noise is worse. Tests on audio signals indicate that, even though the intelligibility of speech is improved by coarse quantizing and fine sampling, listeners prefer fine quantization and coarse sampling. The TV situation will perhaps be similar; that is, people do not like quantization noise.

Some work has been done on adding noise or noise-like signals to the picture before quantization to reduce the contouring effect. In this case, the signal-to-quantization-noise ratio is unchanged, but the quantization noise now has higher spatial frequency and is not as discernible to the viewer. Examples of this technique are quoted in the review paper by Connor et al. (1972).

The total output signal-to-noise ratio, $\left(\frac{S}{N}\right)_o$, can be written from the signal-to-quantization-noise ratio, $\left(\frac{S}{N}\right)_q$, and the signal-to-detection-error-noise ratio, $\left(\frac{S}{N}\right)_e$, as

$$\left(\frac{S}{N}\right)_o = \frac{1}{\left(\frac{S}{N}\right)_q^{-1} + \left(\frac{S}{N}\right)_e^{-1}}$$

For the comparisons presented here the signal-to-quantization-noise ratio is 48 dB, while the signal-to-detection-noise ratio is 41 dB. This results in a 40-dB signal-to-noise ratio, as required for a TASC-excellent picture.

6. .1 Pulse Code Modulation

A very popular digital transmission technique is pulse code modulation (PCM). The message signal is sampled at the Nyquist rate, the sample is then quantized into one of L levels, the information on signal levels is then coded and the code is used to key the transmitter in an appropriate manner. A block diagram of a PCM system is shown in Fig. 24.

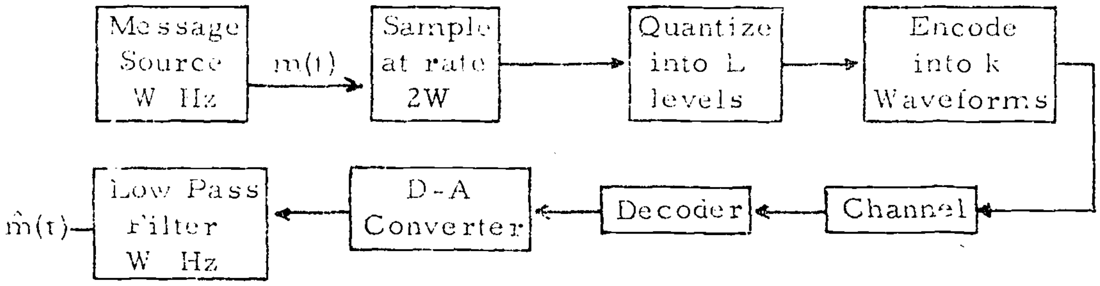


Figure 24. PCM Transmission System.

It is assumed that the analog message, m(t), is uniformly distributed between two limits and since, in general, this is not the case, the signal is usually passed through a nonlinear amplifier that compresses it to fit uniformly in the range of the quantizer. This means that each level out of the quantizer is equally likely to occur, and this results in a maximum amount of information per waveform. At the receiver, the signal out of the D-A converter must be passed through an expander or nonlinear amplifier that gives the output the same distribution as m(t). The compressor and expander are normally called the "compander," and a signal passed through either is said to be "companded." The compander usually does not greatly increase the system cost, since a device to match the signal to the digital equipment is needed anyway. The subject of companding is covered in detail by Smith (1957).

The PCM technique described here is called "coded PCM without delay," which means that the L levels are encoded into k waveforms and that these waveforms are transmitted before the next sample is taken. Coded PCM with delay means that a number of the samples are stored at the transmitter and then transmitted all at once. Since this technique requires storage capability at the receiver and terminal, it is felt that coded PCM without delay is the most advantageous for the CATV application.

The output of the quantizer is equally likely to be one of L possible levels. The number of the level (zero through L-1) can be written in $\log_2 L$ binary digits or bits. So the number of bits per sample is q, where

$$q = \log_2 L \text{ bits/sample}$$

The signal-to-quantization noise ratio is independent of the channel or signaling and depends only on the number of quantization levels used. The signal-to-quantization noise ratio, $\left(\frac{S}{N}\right)_q$, at the output is (Viterbi, 1966),

$$\left(\frac{S}{N}\right)_q = L^2 = (4)^q \quad .$$

For a TASO-excellent picture, the signal-to-noise ratio must be 40 dB or there must be 7 or more bits/sample. Seven bits/sample would mean a signal-to-quantization noise ratio of 42 dB, which is only slightly above the 40 dB desired output signal-to-noise ratio. However, 8 bits/sample gives a signal-to-quantizing noise ratio which is 48 dB, or 8 dB above the desired ratio. Furthermore, practical considerations and ease of implementation would strongly favor 8 bits/sample. Thus, it is assumed that there are 8 bits/sample, or the encoder must encode 8 bits of information into k different waveforms during each sampling interval.

If there are k different waveforms available to the transmitter, each one can carry $\log_2 k$ bits of information. So the number of bits carried by each waveform is

$$a = \log_2 k \text{ bits/waveform} .$$

Thus, there must be q/a waveforms/sample or the sampling interval must be broken into q/a subintervals, and during each of these subintervals one of the k available waveforms is transmitted.

To illustrate this, assume that a video TV signal of approximately 5-MHz bandwidth is sampled at the Nyquist rate, or the time between samples is 0.1 μs. If there are L = 256 levels, q = 8 bits are generated every 0.1 μs, or the digital transmission rate must be 80 M bits/sec. If there are k = 16 different waveforms available, then a = 4 and q/a = 2 waveforms/sample, so that there are 20 x 10^6 waveforms transmitted per second and each waveform carries 4 bits.

If there were no noise in the CATV system, all of the transmitted waveforms would be received correctly and the signal-to-detection-error-noise ratio would be infinite, so the output signal-to-noise ratio would be equal to the signal-to-quantization-noise ratio given above. However, all practical systems have an undesirable noise component so that some of the waveforms are received incorrectly. When a waveform is received incorrectly, the output is different from what it should have been, or there is detection-error noise in the output. The signal-to-detection-error-noise ratio, under reasonable assumptions, is approximately (Viterbi, 1966),

$$\left(\frac{S}{N}\right)_e = \frac{\log_2 k}{4P_e}$$

where P_e is the probability of detecting a transmitted waveform incorrectly. The output signal-to-noise ratio can then be written as

$$\left(\frac{S}{N}\right)_o = \frac{L^2}{1 + \frac{4P_e L^2}{\log_2 k}}$$

The probability of error per waveform, P_e , depends on two main considerations. The first consideration is the ratio of energy in the waveform over the noise spectral density, E_s/N_o , and for all types of signaling, as E_s/N_o increases, P_e decreases. The second consideration is the type of signaling - i.e., the type of waveform transmitted. A sinusoid has three parameters which are easily changed: the amplitude, the phase, and the frequency. Therefore, the signaling methods considered here are: amplitude shift keying (ASK), phase shift keying (PSK), and frequency shift keying (FSK).

6.1.2 Delta Modulation

Delta modulation (DM) is a technique whereby an analog signal is encoded into a sequence of binary digits which are transmitted. It is actually a subclass of PCM but is considered separately, since the equipment required for DM is considerably simpler and cheaper than that required for PCM. This is quite important in a CATV system where there are many subscribers.

There are many different types of DM and the type considered here is generally referred to as simple DM and is perhaps the simplest of the different types. The idea is to sample the message signal significantly faster than the

Nyquist rate. A binary one is transmitted if the message signal has increased since the previous sample, and a binary zero is transmitted if the message signal has decreased since the previous sample.

The realization of a DM system is quite simple, as is seen in Fig. 25. The advantage over a PCM system is that analog-to-digital and digital-to-analog conversion is not required in DM. Notice that the receiver is simply a decision device and an integrator and, if transmission is direct, all that is required is an integrator.

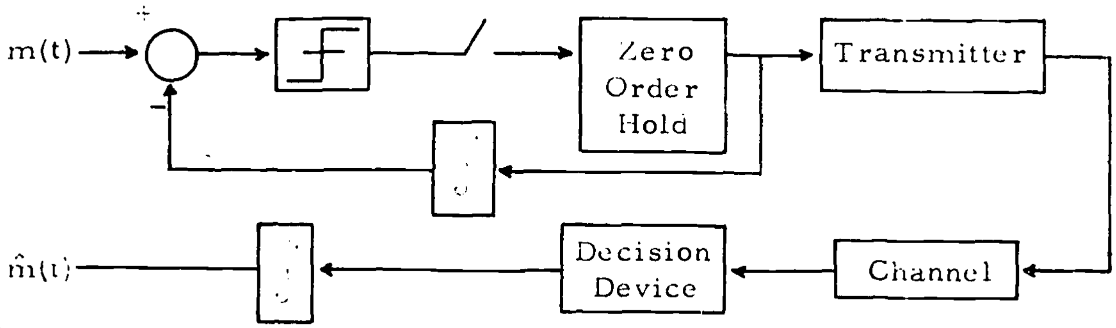


Figure 25. Delta Modulation System.

If the system is properly designed, there are two types of output noise as in PCM: quantization noise and detection-error noise. The signal-to-quantization-noise ratio for DM is approximately (Taub and Schilling, 1971)

$$\left(\frac{S}{N}\right)_q \approx 0.3\, q^3$$

where q has the same meaning as for PCM, i.e., number of binary digits to be transmitted in a half cycle of the highest frequency component. For the same bandwidth occupancy as a binary (k = 2) PSK system, q = 8, i.e., the DM system samples at eight times the Nyquist rate, and the signal-to-quantization-noise ratio is 22 dB as compared with 48 dB for the other PCM systems. By increasing the sampling rate to approximately 38 times the Nyquist rate, the signal-to-quantization-noise ratio can be increased to 48 dB. So a simple DM system must be operated at a very high sampling rate to deliver the performance required for a high quality CATV picture. There are many techniques whereby the sampling rate can be decreased without decreasing the signal-to-quantization-noise ratio, but most require a more complex system, and the primary reason for considering DM is its simplicity.

A general rule is that when high quality is needed, PCM is more efficient than DM, but when less quality is required, DM is more efficient than PCM. Thus, a military voice application would perhaps favor DM, while a commercial entertainment application (such as downstream CATV) would favor PCM.

6.1.3 Comparison of Systems

One of the essential features of system design is comparison of different proposed systems with existing systems. An excellent way to compare communications systems is on the basis of how efficiently they use energy and bandwidth. This involves finding the relative position of the different communication systems on a graph (where one axis is the bandwidth utilization and the other axis is the energy utilization) when all the systems are operating at the same output signal-to-noise ratio.

Let the bandwidth used be denoted B (Hz) and the digital bit rate be R (bits/sec) so that the ratio B/R is a dimensionless number that is the bandwidth utilization, or the bandwidth required to sustain a given bit rate. Clearly, systems with smaller B/R ratios use the bandwidth more effectively, and the ideal (unrealizable) system would have a B/R of zero.

It was pointed out above that E_s/N_o, where E_s is received waveform energy and N_o is noise spectral density, is a main consideration in system design. Rather than using E_s, it is more convenient to use E_b, the received energy per bit. The two are related by

$$E_b = \frac{E_s}{a}$$

where a is the number of bits/waveform, as described above. E_b has units of joules or Watt-sec, while N_o has units of Watts/Hz, so that E_b/N_o is dimensionless. This ratio is the energy utilization, and clearly a system with a smaller E_b/N_o uses the energy more efficiently and the ideal (unrealizable) system would have an E_b/N_o of zero.

The comparison graph is obtained when E_b/N_o is plotted on the vertical axis and B/R on the horizontal axis. As pointed out above, the most desirable system is one that operates at the origin, but there are certain physical limits which prevent this. The capacity of the channel, sometimes referred to as Shannon capacity, is shown in Fig. 26. The meaning of this limit is that any system operating below the curve will have large probability of error. So this comparison technique shows how close to the Shannon capacity a system operates.

Also shown in Fig. 26 is a line of constant slope, and every point on this line has the same signal-to-noise ratio in the channel. It should be made clear that this slope is the channel signal-to-noise ratio and not the output signal-to-noise ratio. For the video portion of a conventional TV the two are the same, but for the other systems discussed here the channel signal-to-noise ratio is less than the

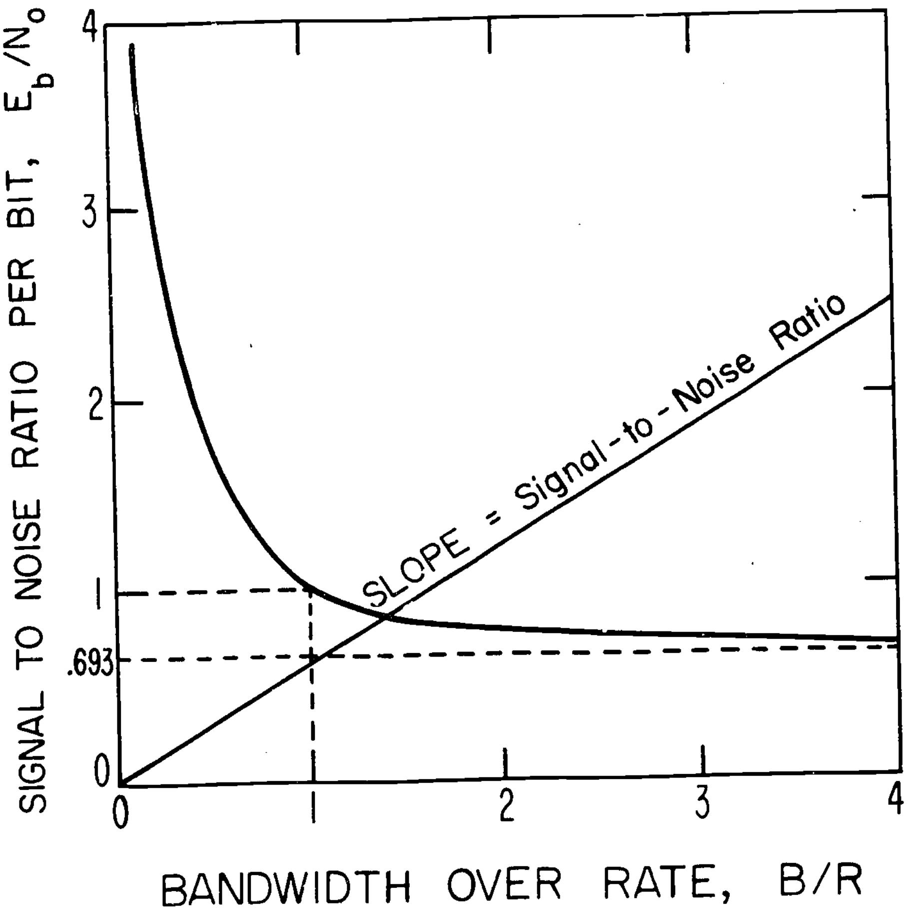


Figure 26. Channel Operating at Capacity.

output signal-to-noise ratio. To see that the slope is indeed the channel signal-to-noise ratio, note that the slope of the line is written as

$$\text{Slope} = \frac{E_b/N_o}{B/R} = \frac{E_b R}{N_o B} = \frac{\text{signal power}}{\text{noise power}}$$

Again, it is pointed out that this is the channel signal-to-noise ratio rather than the output signal-to-noise ratio.

To expand the range of the graph, it is necessary to use log-log paper, and when this is done, all lines of constant slope become diagonal lines, as shown in Fig. 27. Several different systems are plotted in Fig. 27, and all have the same output signal-to-noise ratio of 40 dB, and the digital systems have the signal-to-quantization-noise ratio of 48 dB. Systems with PSK and k = 2, 4, 8, 16, 32, and 64 are plotted along with the same systems for differential phase shift keyed (DPSK) systems. The advantage of DPSK is that the requirement on the local oscillator in the home receiver is not as stringent as with PSK, but the energy utilization is not as good. Also shown in Fig. 27 are points for FSK k = 2, 4, 8, and 16, and a point for DM. The requirements for the digital signaling methods are that the signal-to-quantization noise ratio be 48 dB and that the output signal-to-noise ratio be 40 dB.

The Shannon rate of a continuous source is used to plot two analog transmission systems in Fig. 27 with the requirements that the output signal-to-noise ratio be 40 dB. For both the commercial FM and the TV video, the B/R can only be lower bounded, so that the true operating points are located to the upper right of the plotted point. Since in TV video nearly 70% of the bandwidth uses signal-sideband transmission and less than 20% is double-sideband transmission, it is assumed here that the signal-to-noise ratio improvement factor is that of single-sideband with a synchronous demodulator, i.e., unity. Thus, the channel signal-to-noise ratio is the same as the output signal-to-noise ratio, which is 40 dB. Again, this results in a lower limit, as indicated in Fig. 27, since a conventional TV does not use synchronous demodulation. The non-synchronous demodulation may increase E_s/N_o for TV video over that plotted in Fig. 27 by a factor of from 3 to 8.

From Fig. 27 it is evident that the conventional TV video system uses bandwidth quite efficiently, but does not use the received energy as efficiently as other techniques. Since the other techniques operate at a lower channel

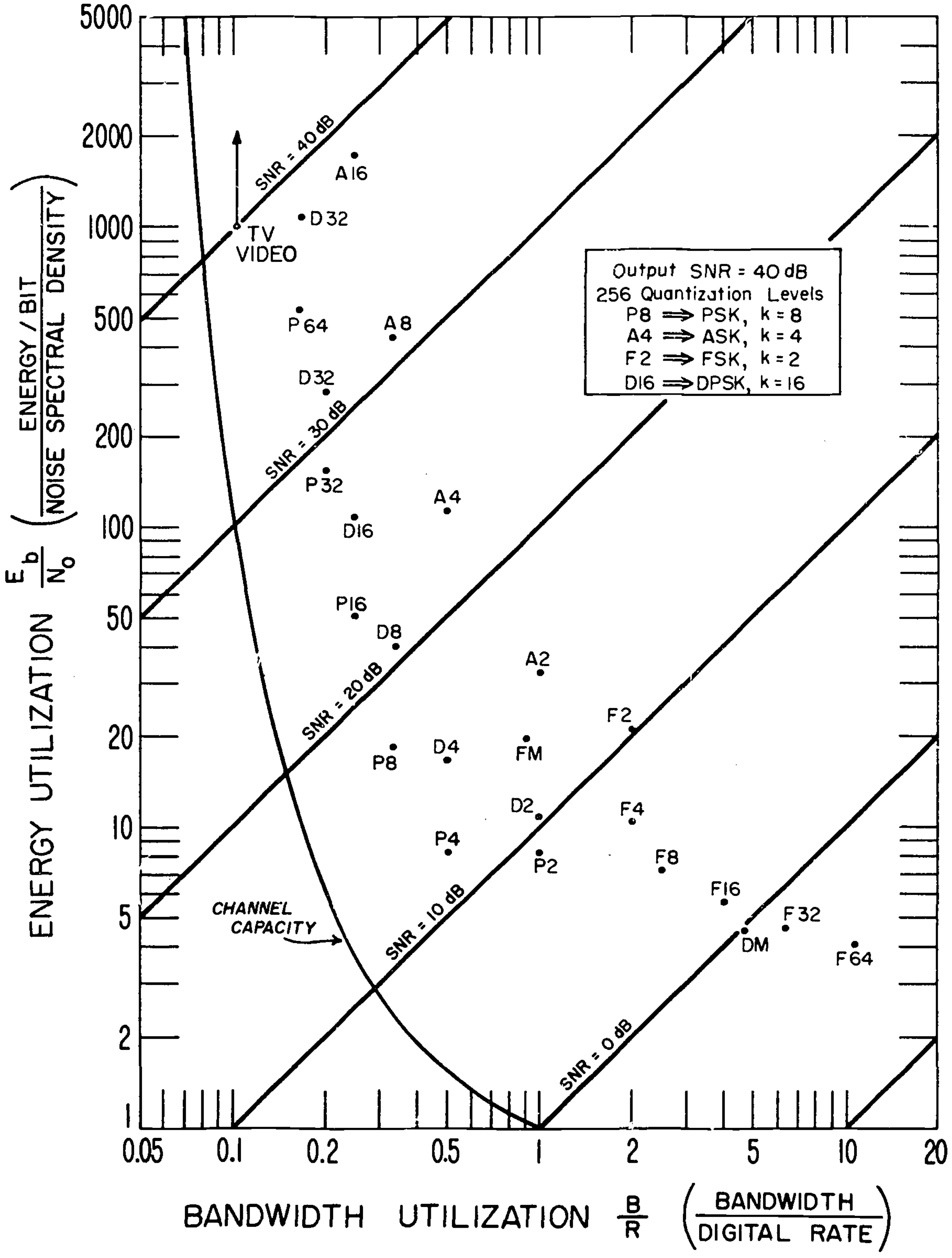


Figure 27. Operating Characteristics of Several Different Communication Systems.

signal-to-noise ratio, they would allow longer CATV systems, or, alternatively, they would allow smaller and cheaper cable to be used.

Since the axes of Fig. 27 are normalized, the graph is applicable for any rate or bandwidth. Thus, it can also be used to compare digital and analog techniques for two-way CATV systems.

6.1.4 Source Encoding

Most of the discussion here has dealt with methods of signaling, or waveform design, to send information over the cable. Another potentially important area for CATV is the encoding of the pictures prior to being sent over the cable, or as it is sometimes called, source encoding. The potential for bandwidth reduction is much greater from optimizing the source encoding method that from optimizing the signaling method (Cooper, 1972). It should be kept in mind that bandwidth reduction may bring about lower transmitting system costs per channel in a CATV system.

Two rather straightforward source encoding methods, PCM and DM, have been discussed briefly; however, there are other techniques which may prove superior. Each PCM sample determines one picture element of one TV frame, and the TV picture consists of a rectangular array of 525 vertical elements by approximately 533 horizontal elements. The number of horizontal picture elements is determined by the sampling interval, and 0.1 μs is assumed here. Using the straightforward PCM encoding with 8 bits/sample, which results in a signal-to-quantizing-noise ratio of approximately 48 dB, 8 bits/picture elements or 8 bits/pel are required.

In any picture there is significant redundancy, and the PCM technique with 8 bits/pel transmits all of the redundancy. Sophisticated coding techniques can reduce the required number of transmitted bits to approximately 1 bit/pel (Wintz, 1972) by not transmitting the redundant information in the picture. Even though the number of bits/pel has been reduced, the signal-to-quantizing-noise ratio has not decreased. This reduction in bit rate has been obtained at the expense of more sophisticated encoding and decoding equipment.

The difference between the straightforward PCM encoding and a sophisticated encoding scheme is that PCM encodes only one pel at a time, while the sophisticated technique is at any one time encoding many pels. It is likely that the optimum technique is to encode only a few pels at a time. This would allow relatively simple encoders and decoders, but would still result in significant reductions in the number of bits/pel. A promising technique is to encode the differences between pels; this is called differential pulse code modulation (DPCM). The DM technique described above is a special case of DPCM and, in fact, it can be said that PCM is a special case of DPCM. Experimental evidence (Connor et al., 1972) suggests that the number of bits/pel for PCM can be approximately halved by using only the previous pel and current pel. This means that with a relatively simple encoder and decoder, the bit rate and the required bandwidth could be approximately halved. This points out an additional advantage of digital transmission, i.e., the picture redundancy can be removed much more readily in a digital system than in an analog system. Source encoding of images is also discussed in Volume 5.

The DPCM techniques were not presented in the previous comparison, since the analysis is much more difficult for DPCM than for PCM as DPCM performance depends on the second-order picture statistics, while PCM does not. A recent special issue of the Proceedings of the IEEE (July, 1972) has many examples of DPCM.

The source encoding alluded to thus far has been picture encoding, i.e., the structure of the picture image is used to reduce the data rate. In addition, if the signal has some structure, as is the case for the standard color television signal, it can also be exploited to reduce the data rate. The color television signal can be broken into three components and a sampling scheme used on each (Golding and Garlow, 1971). The saving in rate is not as great as that for picture coding but is significant.

6.1.5 Cascadability of Transmission Systems

A matter of extreme importance in a CATV system is the potential length of the system, and this is determined by the trunk amplifiers. The signal-to-noise ratio in any trunk system is degraded by each trunk amplifier and the channel signal-to-noise ratio after the m^th amplifier, SNR_m, is

$$SNR_m = SNR_h / mF$$

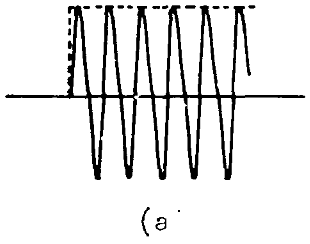
where SNR_h is the signal-to-noise ratio at the head-end and F is the noise figure of the amplifiers. The signal-to-noise ratio at the head-end can be calculated by assuming the rms signal level is 1mV, which is the level required for a noise-free presentation on an ordinary TV set. If the noise power is taken as the thermal noise at room temperature in a 4.2-MHz bandwidth, the signal-to-noise ratio at the head-end is approximately 60 dB. Further, if the output signal-to-noise ratio at the receiver is required to be 40 dB, the mF product must then be 100. For example, if the noise figure of the amplifier is the typical value of 10 dB, the signal-to-noise ratio will be degraded after only 10 amplifiers.

The mF value allowable when the transmission is digital can be found by using Fig. 27, noting at what value of channel signal-to-noise ratio the particular digital technique will operate and finding mF by using the above equation. For example, assume that transmission is by PSK with k = 4, which, according to Fig. 27 will deliver a 40-dB output signal-to-noise ratio at a channel signal-to-noise ratio of approximately 13 dB. This represents a signal-to-noise ratio degradation, from the head-end, of 50,000 (47 dB) and, accordingly, the allowable mF is 50,000. If the noise figure is 10 dB, this means that 5000 amplifiers can be cascaded. This is a rather startling improvement over the conventional amplitude-modulated transmission system in which only 10 amplifiers could be cascaded.

It is noted from Fig. 27 that a wideband FM system similar to commercial FM would also allow an mF of approximately 50,000, but would use almost twice as much bandwidth as PSK with k = 4.

The cascadability depends on the distortion caused by nonlinear effects in the amplifiers, as well as by the thermal noise added by the amplifiers. The analysis for the digital systems presented here depends on only the thermal noise for two reasons. First, the only nonlinearity that has been well studied with respect to digital transmission is the hard limiter or infinite clipper. The reason for this is that most satellite repeaters are hard limiters or reasonable approximations. Results for digital signals through slight nonlinearities are not readily available. The second reason for not considering nonlinear distortion for digital signals is that it will not be as severe a problem as it is for conventional CATV systems. Single sideband, which is similar to the conventional TV video signal, is perhaps one of the modulation methods most susceptible to nonlinear distortion, as is illustrated in the next paragraph.

In Fig. 28(a) the transmitted waveform generated by a step is shown for double sideband modulation. This would be the case in going from a light to dark region in a picture, which is very common in TV presentation. The same transmitted waveform for conventional TV video is shown in Fig. 28(b). Note that while the conventional TV video



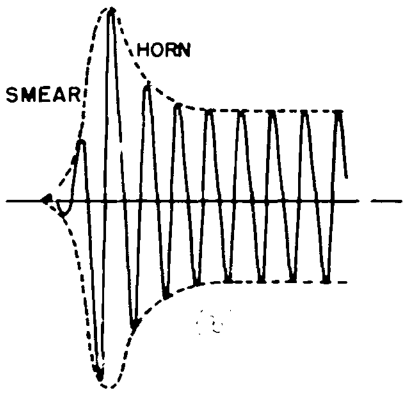


Figure 28 (a). Double Sideband Modulation Response to Video Step.

Figure 28 (b). Vestigal Sideband Modulation Response to Video Step.

signal does take less bandwidth than the double sideband modulation signal, it requires more dynamic range in the system, i.e., it is more susceptible to nonlinear distortion. The peak in the step function response for TV video modulation is called the "horn" and the spreading of the step function is called "smear" by TV engineers. The important point is that faithful transmission of a video step (which determines horizontal resolution in the TV picture) requires more dynamic range than if double sideband modulation were used. The digital transmission systems discussed in the previous section would require the same or less dynamic range than double sideband modulation, so that nonlinear effects in digital transmission are not likely to be as large a problem as in present systems.

6.1.6 Economic Advantages of Digital Transmission

The main advantage of digital transmission (or any modulation technique that exchanges bandwidth for channel signal-to-noise ratio) is that long-distance trunking will be considerably cheaper than if conventional trunk extension techniques were used. Kirk and Paolini (1970) suggest that digital transmission is competitive with conventional techniques, but do not compare system costs. A forthcoming report by the first author compares the relative cost of transmission systems for three different approaches to the trunk extension problem. The first approach is to use larger diameter cable and place the amplifiers farther apart. The second approach is the sub-band trunking described previously, where only the lower frequencies are transmitted in several parallel cables. The third approach is to use several cables, but with modulation methods which trade the additional bandwidth for signal-to-noise ratio.

The cost of a transmission system is defined as the total cable cost plus the total amplifier cost. The terminal equipment is not included, as it is difficult to compare this equipment on a cost basis. By using a plot similar to Fig. 27, it can be shown that for a forty-channel system, the first technique of using a larger diameter cable is cheaper than the sub-band trunking method, but the advantage decreases as trunk lengths increase. More importantly, the third technique using digital modulation is shown to be cheaper than either of the other two as trunk lengths increase. The digital technique used is PCM with ASK, as described previously, without any source encoding. If source encoding is used, the economic advantage would swing even more heavily to digital trunking.

An example of the cost advantage of a digital, three-cable system over a conventional system for a 40-dB output signal-to-noise ratio is shown in Fig. 29. The vertical axis is how many times more expensive the conventional system is than the digital system. The amplifiers for the three-cable system are assumed to be in the same case and use the same power supplies and compensating circuits. If the cost of a unit is determined mainly by the case, power supplies, and compensating circuits, the cost factor follows the upper limit. If, however, the cost of a unit is mainly due to the cost of the individual amplifiers, the cost factor goes to the lower limit. In all likelihood, the cost factor is somewhere between these limits.

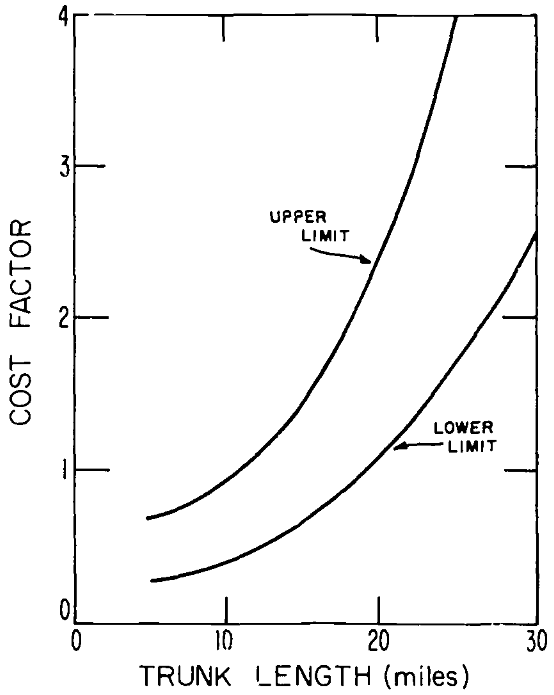


Figure 29. Cost Advantage of Digital ASK System Over Present CATV System Versus System Length.

If either of the source encoding methods referred to earlier are used, the transmission costs for the digital system will decrease even further.

6.2 Multiple Access for Two-Way Systems

There has been a great deal written about possible services and benefits of a two-way CATV system. There are many different techniques that can be used to achieve two-way operation, and it is highly desirable to understand the advantages and disadvantages of each. Multiple access can be defined as the collection of techniques that allow many users to nearly simultaneously gain access to and use of a common wideband communications channel. Since the signals co-exist in a common channel, they must be separable at the receiver, and there are many different ways of designing the signals so they can be separated.

There are different ways of classifying multiple-access systems, and the one that is used here is shown in Fig. 30, where three different types of channel assignments are indicated. There are perhaps other types of channel assignment, but the three indicated here appear to be the most important for the CATV application.

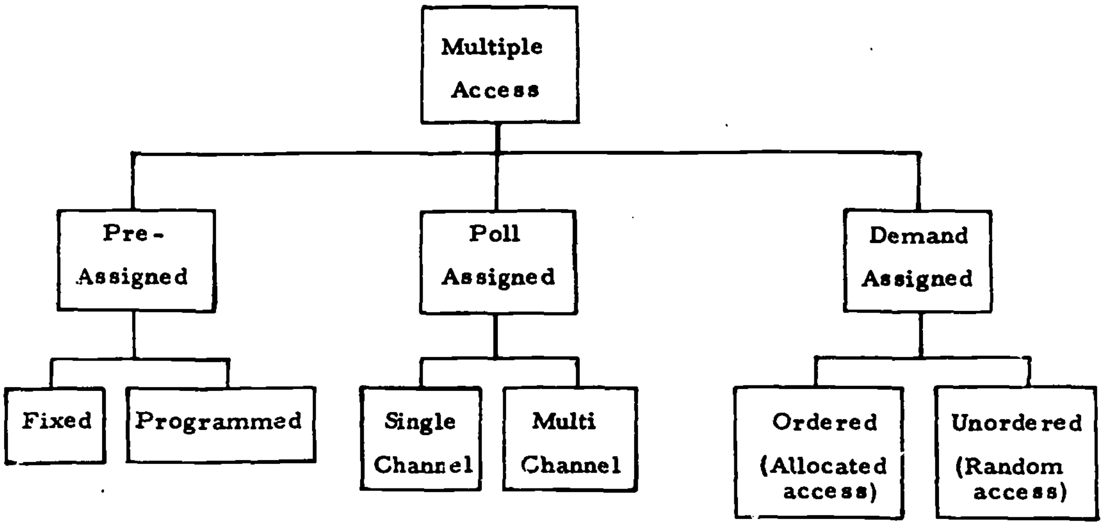


Figure 30. Classifications of Multiple-Access Systems.

The most straightforward method of assigning channels is by prior agreement among the users and the channels are said to be "pre-assigned." The channels can either be assigned on a fixed basis or on a programmed basis. The assignment on a fixed basis means that each user always uses the same channel and no other user ever uses this channel. This technique is very good when all users have a high duty cycle. When the user traffic can be pre-arranged and the users have less than a unity duty cycle, channels can be time-shared on a pre-arranged programmed basis. The advantage to this is that fewer channels are needed, since a number of users share the same channel. The pre-assigned channel technique may find use in CATV systems where large institutional users are involved. However, for the case of two-way service to the home, the typical user has a low duty cycle and the messages cannot be scheduled, so the pre-assignment technique would likely be inefficient.

A second method of assigning channels is by polling the user population regularly to determine which users desire access and then assign channels on the basis of the poll. The single-channel poll-assigned approach is currently in use in some experimental CATV systems, since it perhaps results in the least expensive system. Each user is assigned a particular code; by using this code the controller at the head-end polls each user sequentially in time and each user terminal indicates whether it has a message. After completing the poll, the controller orders the requests and sequentially allows each user to transmit. After all the requests have been serviced, the controller polls the entire user population again. It is clear that only one user can transmit at a time and the signals can always be separated. The major advantage to the single-channel poll-assigned technique is that each user transmits the same signals since users transmit only on request from the controller. The major disadvantage is that of all the techniques, the single-channel poll-assigned method will result in the longest waiting time for a user to be serviced for two reasons. The first is that while this technique uses bandwidth efficiently, it uses time inefficiently since no users are being serviced during the polling time. The second reason is that only one user can be serviced at a time. If the average service time is small, the average waiting time will be small; however, as the two-way services become more sophisticated, the average service time will become longer, resulting in a longer average waiting time. It appears that the single-channel poll-assigned technique will prove unacceptable when users have voice transmission, as would be required in a two-way educational service. The poll-assigned technique can be used with multiple channels, but the main advantage of simplicity is lost, and it is perhaps desirable to consider a technique that uses time more efficiently.

The third method of channel assignment is demand-assigned, where the channels are assigned on the basis of user demand. The assignment can be on an ordered basis where the signals are kept separate by the fact that they are orthogonal, or on an unordered basis where signals are mutually interfering. For ordered, or allocated, access it is assumed that there is centralized control, since decentralized control is not practical for a CATV application. A user desiring a channel makes a request on a separate channel sometimes called the "order wire" and the controller responds on this channel with one of two messages. Either no channels are available, in which case the user is said to be "blocked", or an available channel is assigned to the user. The advantage of this technique is that in the CATV application, bandwidth and time are used more efficiently than the pre-assigned or poll-assigned techniques. Also, the average waiting time of a demand-assigned ordered-access technique will be less than that for a poll-assigned technique.

A queuing analysis, which gives the average waiting time and blocking probability for allocated access, is given in Volume 5.

The second type of demand-assigned operation is unordered or random access in which users transmit whenever they wish without the necessity of a central control. The signals are transmitted on the same wideband channel and are kept separate by a low correlation code. Besides the advantages of zero waiting time and no central control, random access has two additional advantages over ordered access. The first advantage is that transmissions are naturally secure, i.e., the required low correlation codes provide a measure of privacy and security . The second advantage is that the user terminal always sends the same set of waveforms rather than having to send different waveforms for different channels. This may result in simpler and cheaper signal generators for home terminals. The disadvantage of random access is that, due to the mutual interference, performance will decrease as the number of simultaneous users increases.

Four characteristics of the multiple-access classification are given in Table 5. A "no" in the first column means that the performance is constant, while a "yes" means that performance degrades as the number of simultaneous users increase, which is sometimes said to be "graceful degradation." When a random access system is overloaded, there is still zero access delay time but communication may be difficult or impossible. The last column relates to terminal expense, and in order to reduce equipment complexity and cost, it is desirable to always use the same transmitted signals. This means that expensive items, such as automatically tunable oscillators, would not be required in the home terminal. This is important since one of the most significant considerations in the viability of a two-way CATV system is an inexpensive home terminal. So, in Table 6 it is desirable to have a "no" in each column; the only type which does is a fixed assignment system. However, a fixed assignment system uses bandwidth inefficiently when the users have a small duty cycle.

Type of Assignment	Mutual Interference	Access Delays	Central Control Required	Variable Signals Required
Fixed	No	No	No	No
Programmed	No	Yes	No	No
Poll (Single)	No	Yes	Yes	No
Poll (Multi)	No	Yes	Yes	Yes
Ordered	No	Yes	Yes	Yes
Random	Yes	No	No	No

Table 6. Characteristics of Multiple-Access Classifications

There are many different design techniques for signals that achieve the different types of multiple-access. The two most common are frequency-division multiple-access and time-division multiple-access; these are discussed by Magill (1966). Two other techniques, which are specifically designed for random access, are spread-spectrum multiple-access and pulse-address multiple-access; these are also discussed by Magill (1966). Another very promising design technique is time-frequency-coded multiple-access, which is discussed by Cooper (1970).

6.3 Optical Waveguides

6.3.1 Introduction

As the industry evolves from primarily CATV to CATS (cable teleservices), the bandwidth demands put on the system will steadily increase. If we examine the possibility of providing truly broadband two-way service to each subscriber or to each remote office (Healy, 1968), the present cable system appears to be inadequate. It is true that coaxial cables could be improved to increase their communication capacity, but it is unlikely that required improvements would render then viable. In view of recent advances in telecommunication technology, it would be much more prudent to examine entirely new concepts in providing cable services. This leads to to the idea that glass fibers could possibly be used in lieu of coaxial cables in future systems. The possibility becomes all the stronger when the advantages of digital techniques are examined; the advantages have a price and that price is increased capacity in the system. Thus, a cable with additional capacity is again required.

There is some speculation that glass fiber waveguides operating at optical frequencies would be capable of providing data rates on the order of a Gbit/sec (10^9 bits/sec). The need for these links, then, depends on public acceptance of the innovative concepts now being suggested. The notions of electronic mail, checkless economy, electronic newspapers, and random access to a library, including a TV library, are predicated on the availability of a truly broadband link into the home. If communications capability is interchanged with travel, as suggested by Healy (1968), the requirements will become even more taxing. The "remote office" concept suggested in this same article will further test the capability of future CATS networks. The queuing analysis in Volume 5 indicates clearly that many of the new services currently being considered just will not be possible with the present system due to lack of capacity. The increased capacity of the optical fiber would allow many new services.

There is another factor in the consideration of optical communications: the respect for gradual generational steps in advancing technology, i.e., steps which build on existing knowledge. Thus, as demands on communications channels increased in recent decades, an orderly change from one generation to the next in communication systems has been witnessed.

Capacity increased in an orderly fashion as we moved from telegraphy to open wire telephone lines to carrier telephone to coaxial cables. The evolution has been such that the various media have coexisted and developed according to the needs; they have grown side-by-side. As the demands increase and we look to new media to satisfy those demands, we continuously examine succeeding generations of technology. The glass fiber system may not be considered the "next generation" by some. Instead, it is an entirely new concept and will encounter some resistance in its evolution. It uses optical frequencies and a nonconducting cable. Many of the intuitive concepts used by current workers would simply not apply. In addition, it is currently untested, leading to further opposition. Opponents will argue that the evolution can be orderly and viable only if we continue to build on existing technology. They present the rather convincing argument that an optical waveguide system still has several unresolved basic problems.

These arguments must be tempered by the realization that the accelerative technological thrust, as suggested by Toffler (1970), will tend to blur the traditional generational lines. Toffler suggests that technological innovation consists of three stages: the creative, feasible idea; the practical application; and diffusion through society. These three stages are linked in a perpetuating cycle which, when completed, tends to generate new creative ideas. He points out that the time between original concept and practical application is being greatly reduced; today's social devices provide the vehicle for this accelerative thrust. Extending that idea, it is easy to see that there is a definite tendency to by-pass what would have been the next logical generation of technology if the demand is adequate.

6.3.2 Fiber Development

The use of dielectric strands in the transmission of light frequencies has evolved slowly, beginning with individual fibers and bundles which were quite crude by today's standards. They served their purpose well, however, and the high loss was of little consequence since they were used to transmit light over only short distances. They appeared in various measurement paraphernalia and image producers for inspection of inaccessible places. Because of the high losses, their use in teleservices links was not considered seriously until it was discovered that the fundamental loss mechanism in certain glass materials is quite low at certain frequencies in the visible and near-infrared region of the spectrum.

Of course, the fundamental loss mechanism only puts a lower limit on the attenuation to be expected after the bulk glass is drawn into fibers. To elaborate on this latter point, note that the losses in fibers and in the bulk glass from which fibers are drawn are due to two distinct mechanisms: absorption and scattering. In bulk glass material, the loss is due largely to absorption and in optical quality glass this is felt to be because of the presence of ionic impurities, especially the transition-series elements. It has been estimated that most ionic impurities will have to be maintained at no more than about one part per million. Absorption loss in the fiber should be about the same as in the bulk material.

Because absorption loss is a function of frequency, there is not complete freedom in choosing frequency and glass material (Pearson and French, 1972; Li and Marcatilli, 1971). In recent years there have evolved some rather sophisticated methods of measuring the absorption loss in various bulk materials (Tymes et al., 1971). This has led to a better foundation on which to base a decision regarding material and frequency. Additional work was reported at the

1972 Las Vegas Conference (OSA Integrated Optics Conference, 1972). Using a calorimetric technique which is precise to within a fraction of a dB per km, Pinnow and Rich (1972) measured both absorptive and scattering loss in various glass samples. They found that at 1.06 μm wavelength (Nd:YAG laser), a fused silica sample had absorption loss of only 2.3 ± 0.5 dB/km. This is the lowest value yet reported in solids and it indicates that less than 10 dB/km total attenuation can realistically be expected from state-of-the-art glasses. Table 7 gives the results of measurements on other samples, as reported by Pinnow and Rich (1972).

Sample	Absorptive Loss (dB/km)
Suprasil W1	2.3
Suprasil 1 (A)	12.1
Suprasil 1 (B)	4.3
Infrasil	18.3
Corning 7940	43.0
Dynasil 1000	67.1

Table 7. The Absorptive Component of Optical Attenuation at 1.06 μm.

The probable fundamental scattering loss in the bulk material is Rayleigh scattering, caused by minute inhomogeneities frozen into the glass when it solidifies (Kapron et al., 1970; Osborne, 1970). It is reasonable to expect the Rayleigh scattering in the fiber to be about what it was in the bulk material.

Since Rayleigh scattering loss and absorption loss are expected not to increase substantially as the bulk material is formed into a fiber, there remains the crucial question of other induced scattering loss due to fabrication. Perhaps the most crucial possibility in this regard is the irregularity which may be induced at the core-cladding interface because of the fabrication. Some rather pessimistic predictions have been made regarding the tolerance on the interface (Marcuse, 1969a, b, c; 1970), but workers at Corning Glass Works have reported remarkable success in producing a fiber which has total loss only slightly greater than the measured loss in the bulk material (Tymes et al. 1971).

It is interesting to note that until recently there has been a rather pessimistic attitude about the possibility of producing a low-loss fiber. However, in 1970, Corning Glass Works' scientists announced they had produced a 30-meter section of fiber having a total loss of only 20 dBkm (Kapron et al., 1970). Since that time, they have improved the production techniques and now have 1000-ft fiber bundles of nominal 20 dB/km attenuation. Strictly speaking, these bundles are not yet production items, but it is fair to say they have come out of the laboratory. At this writing, the

20-dB/km fiber bundle is quite expensive ($30/ft) and delivery could not be guaranteed, but clearly the state of the art has advanced considerably since the first announcement two years ago. In late 1972 Corning announced the development of a laboratory fiber 0.55 km long having only 4 dB/km total attenuation. The attenuation for this newest fiber is shown in Fig. 31.

The original low-loss fiber (1970) was a single-mode geometry at 0.6328 μm, whereas the newest fiber is multimode. To understand the full meaning of this, we refer to Fig. 32, which gives a pictorial representation of a (single-mode) fiber. The core and cladding have refractive index n and n, respectively, and the core radius is taken as a. We define a normalized frequency, V, as

$$V = \frac{2\pi a n_1}{\lambda} \Delta$$

where

$$\Delta = \sqrt{1 - \left(\frac{n_2}{n_1}\right)^2}$$

and λ is the free space wavelength. A fiber will support only a single mode if $V \leq 2.405$. As V increases beyond 2.405, the number of modes which will propagate increases as

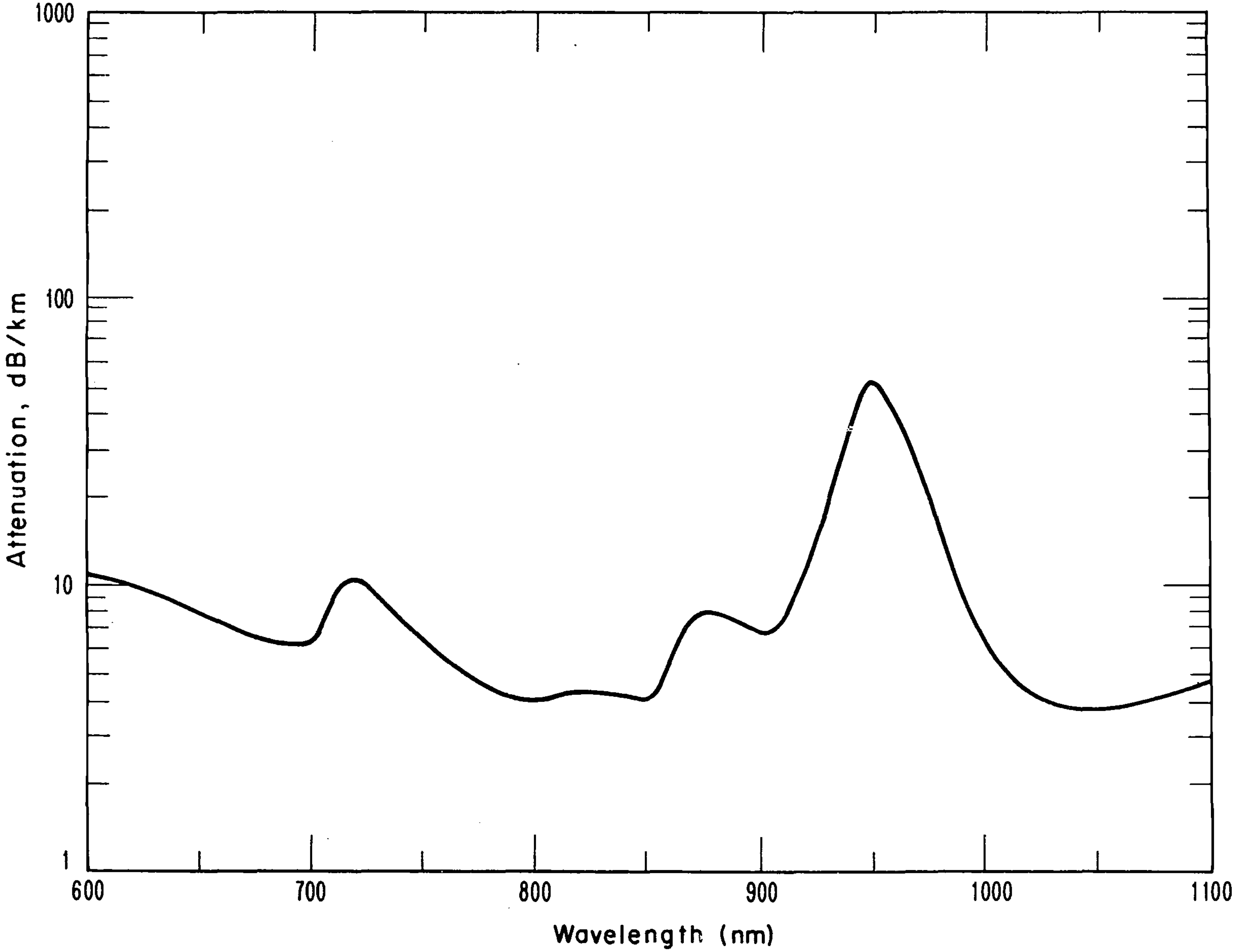


Figure 31. Attenuation of Optical Fiber. (Courtesy of Corning Glass Works.)

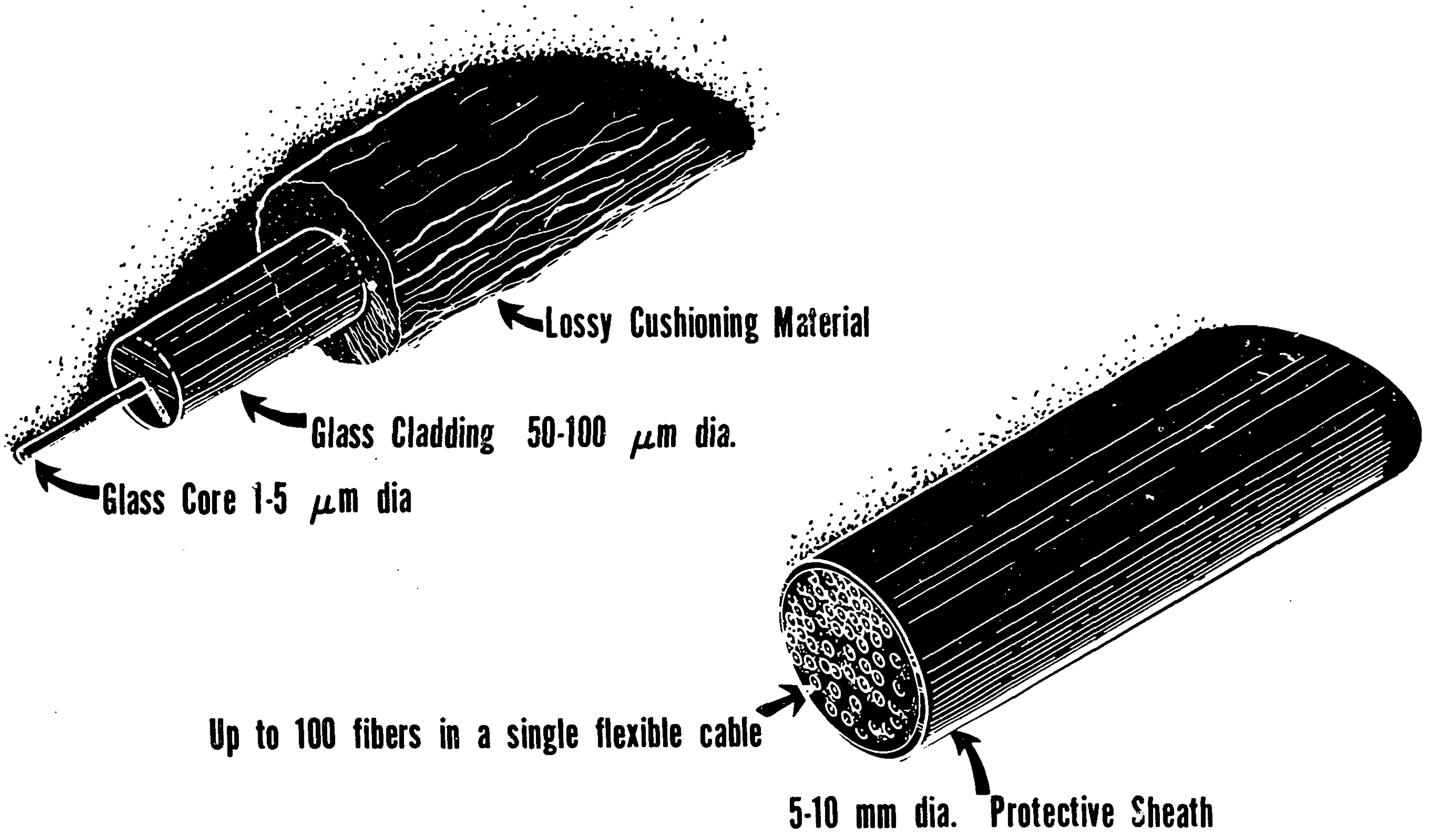


Figure 32. Single-Mode Optical Fiber.

the square of the radius or, alternately, the square of the frequency.

Clearly V involves the important operational parameter f and also the manufacturing parameters a, n_1, and n_2. If the fiber supports only one mode, there will not be interfering modes and, hence, there will be improved communication capacity. If another mode propagates at another phase velocity, the two modes may add out of phase, causing degradation of the signal and, hence, reduced capacity. V can be kept small by having small core radius (a) or small contrast (Δ). However, these are manufacturing parameters and their control to within the desired limits may not be possible or economically feasible. Specifically, if $\lambda = 0.6328$ μm (He-Ne gas laser) and $n_1 = 1.5$ a value representative of glasses having reasonable loss in the frequency range of interest), then V is less than 2.405 if the product of radius, a, and the contrast, Δ, is less than about 1.6×10^{-7}. If $n = 0.99n_1$, then a be no greater than about 1 μm. Thus, the manufacturing requirements are rather stringent for single-mode geometry. Reports thus far indicate that manufacturers are able to repeatedly produce a fiber for which n_1 and n_2 differ by about 1 percent and the core radius is less than 1 μm. Unfortunately, information is not yet available on the cost of these seemingly stringent requirements.

For reasonable values of contrast, Δ , a fiber is single moded only for sufficiently small core radius, typically a few microns. Source energy can then be coupled into the fiber efficiently only with a coherent laser source. In principal, this causes no problems, but in practice we can expect that, for the near-term applications, more inexpensive light-emitting diodes will be used as signal sources. Since LED's emit incoherent radiation into a large cone, coupling efficiency is intolerable unless the core radius is increased; thus, multimode fibers become an important consideration, especially if the fiber is free of inhomogeneities which cause substantial mode conversion. The use of LED's with multimode fibers will allow moderate data rates at a potentially reasonable cost, since the cost of the fiber would presumably be reduced and the source is small, reliable, requires only modest power supplies, and is easily modulated. Thus, if cost or simplicity is an important consideration, then multimode fibers are quite important, especially if the communication requirements are not severe. An additional disadvantage of the LED source is its temporal incoherence, or wider spectral band (typically 11-15 x 10^{12} Hz). This further limits communication capability because of signal dispersion. This is discussed briefly in the following.

In most waveguides the phase velocity of the propagating wave depends upon the frequency. As a result, all signals except CW signals will undergo distortion as they propagate through the guide.

The dispersion is generally due to two separate and distinct factors: (1) the dispersion due to the waveguiding nature of the structure and (2) the change in electrical characteristics of the material as frequency changes. In a coaxial cable, neither of these is the limiting factor; the signal attenuation normally determines amplifier spacing. For the low-loss fiber, the situation is much more complex since the dispersion is expected to determine spacing of the repeater. Phase and group velocities are influenced not only by the waveguide characteristics, but also by the fact that the energy travels in a dielectric (glass) which displays frequency-dependent characteristics. If the fiber is multimode, the interaction of the various modes will be the determining factor in repeater spacing. Attempts to measure multimode effects have been frustrated by the inability to measure mode conversion. If fiber inhomogeneities cause energy to be scattered into all permitted modes, the dispersion can be substantial because of the variation of group velocity with mode number.

Like any other open waveguide, the optical fiber has both advantages and disadvantages relative to the closed guide. Since the electromagnetic energy is not absolutely confined to the guiding structure, there is incomplete shielding and there can be radiation due to discontinuities. The parameters can be adjusted to more tightly bind the wave to the interface, however, and this will reduce the effect. This is not a crucial consideration, since the loss due to a bend is small unless the bend is very sharp.

In open waveguides, concern must also be given to the question of cross talk between adjacent lines. Electromagnetic energy may be expected to couple continuously from one line to another as two lines run parallel for any substantial length unless they are shielded. For fibers, effective shielding is provided by the cladding. Since the field decays approximately exponentially in the cladding region, the field will be very weak at the cladding - air interface provided the cladding is thick enough. A thickness of several tens of wavelengths is generally called for in order to provide the mechanical strength required. The coupling between adjacent lines is then very small indeed, removing another major objection to open waveguides. It may be that bends would complicate this situation, since adjacent lines which are bent could couple more strongly; this would be due primarily to radiation from one line to another. Very little is known of this kind of interaction at present, but it is unlikely that serious problems would develop.

Another potentially worrisome problem deals with methods of joining fibers. The amount of energy lost at a joint depends on the degree of misalignment. Index matching liquid can be used to reduce the effect of misalignment. If detachable connectors are used to join the ends, then axial separation is also of concern. Bisbee (1971a, b) has studied detachable connectors as well as fused connections. The losses were on the order of 10 percent, indicating that joining techniques giving acceptable loss can be expected.

Evidence seems to indicate that the tensile strength of processed fibers is about 1/5 of that of virgin fibers. The reduction is felt to be due to the abrasion encountered in the jacketing process. By using an electroless metal plating scheme, a very thin fiber coating can be accomplished which protects the fiber and the tensile strength is preserved, even during jacketing (Goldfarb, 1972).

Hostile environments would probably not deteriorate the fiber since glass is generally quite corrosion resistant. Fibers have been exposed for short periods to temperatures as high as 1000° C and to 800° C for as long as 30 minutes with no deteriorating effect (Bielawski, 1972).

6.3.3 Economic Considerations

The economics of any communication system depend upon the response time required and the utilization of capacity. Clearly, if a response time on the order of days is acceptable, then the Postal Service provides the most economical way to communicate. When considering real-time communications, user cost decreases with increasing total system utilization. In the early days of telephone, one pair of wires was required for every telephone; this meant that the cost per telephone channel was quite high and the cost of the system was, of course, proportional to its capacity. As technology advanced, it became possible to multiplex several separate carrier frequencies on each pair of wires and the cost per subscriber dropped substantially. Multiplexing additional carrier frequencies onto a single wire pair demands the use of even higher frequencies. Since each communication channel requires a fixed bandwidth and a guard band, the limitations become obvious. As the frequency increases, attenuation and signal distortion inevitably result unless special cables are used which can suitably transmit the higher frequencies. This usually means more capital investment and more sophisticated terminal equipment. Thus, the economics involve the trade-offs between capacity and cable or line costs and more sophisticated terminal equipment at reduced spacing.

There are other factors which cause the economics picture to be rather difficult to interpret. These stem from the demand for diversity in today's technologically-oriented society. Thus, we request (1) a diversity of circuit lengths including different physical environments; (2) a diversity of services in the same network; (3) compatibility with new devices and innovations as they become available and connect onto the system; and (4) some redundancy along certain key routes to protect against special hazards which may cause a link to become inoperable. These lead to a complexity of the transmission network resulting in profound economical ramifications. This is discussed by Abraham (1960), who presents concise but lucid reasons for the varying costs of a communications link. There are many different types of systems, each presenting almost unique cost trade-offs. The variation in cost stems from the very complicated interrelation of signal-to-noise ratio, repeater gain, etc. Furthermore, the interrelations or cost trade-offs change with time. The cost per circuit mile will depend upon utilization, among other things, and this changes from year to year. Likewise, the relative cost of materials and manufacture are constantly changing.

All of these factors serve to point out the difficulty associated with an economic evaluation of the optical fiber. There is a crucial lack of information regarding relative cost of terminal equipment, fiber manufacture, maintenance, etc. Nevertheless, some relative assessments can be made, as were done by the British Post Office (Bray, 1970). In that study, the British scientists studied the 4- and 9-mm coaxial cable and compared the data with the proposed single-mode optical fiber light guide. Their conclusions were stated at the 1970 IEE Conference on Trunk Telecommunications:

1. The optical fiber system at 1 km repeater spacing and 120 Mb/s breaks even with 4-mm coaxial cable at this bit rate, but would offer substantial cost advantage if the spacing could be increased to 2 km;
2. Optical fiber systems at 1 km repeater spacing and 480 Mb/s would compare favorably with 9-mm coaxial cable at this bit rate, but would offer a considerable advantage if the spacing could be increased to 2 km.

In these statements, repeater spacings of 1 km and 2 km correspond to fiber losses of 20 dB/km and 10 dB/km, respectively. While the study was directed to the British system, it is probably true that the conclusions would be valid for most American communication needs. If the capacity of the optical fiber exceeds 480 mB/s, which seems plausible, its relative advantage would increase.

While some of the factors entering into the optical cost assessment are relatively uncertain, others are felt to be of only limited variability. Nevertheless, the cost study indicates that there is good and sufficient reason to further pursue the study and possible development of the optical fiber for use in lieu of coaxial cables.

6.3.4 Summary of Optical Waveguides

Since the use of non-conducting strands of glass for cable teleservices is likely to be a new concept to many practicing engineers, the characteristics that a fiber would offer are listed here. Some of these items have not specifically been discussed in the text; in those cases, a discussion is felt not to be needed. Comparison with conventional coaxial cables is inserted, as appropriate.

1. Electromagnetic interference (EMI).

   Even though a fiber is "open" in the sense that there is no complete electrical isolation of the guided wave, the field structure is such that essentially complete isolation is, in fact, accomplished. Also, the fiber is essentially immune from electromagnetic pickup from other sources.

2. Size, weight, and flexibility.

   The use of fiber bundles offers substantial size and weight advantage over the coaxial cable counterpart. The fiber is flexible and even if it were twisted into a tight bend, the effect would be negligibly small. This implies a reduced installation cost; the flexibility and light weight also imply that installation would be very simple. Figure 32 shows typical dimensions.

. Environmental factors.

The melting point of glass is well above the maximum rated temperature of electrical insulation. The fiber should be quite immune to mechanical fatigue as well. Tensile strength might be a problem, but even that can be overcome with a thin metal coat to protect the virgin fiber. Corrosion resistance of glass is generally better than the copper counterparts and hence deterioration of the fiber is not likely.

4. Electrical isolation.

Fibers would provide complete isolation of source from receiver, there being no electronic ground required. This has several advantages:

a. The receiver and transmitter can be designed independently.

b. Repair of the fiber in the field could be accomplished even while the equipment is turned on.

c. Optical fibers could be used to traverse hazardous areas without fear of a short circuit causing ignition of volatile fumes. In some cases, this may be a very important consideration.

5. Cost.

Currently available high-loss fiber bundles generally sell for about $0.10/ft in large quantities. Since the potential market for low-loss fibers is substantial, one could assume that developmental costs might be offset by the volume cost reduction, bringing the eventual cost to about the same level ($0.10/ft in large quantities).

6. Operational factors.

a. The attenuation of the most advanced fiber is about 4 dB/km and is essentially independent of frequency over the band of interest. Attenuation in coaxial cables is frequency-dependent; for RG 11/U cable at 100 MHz, the attenuation is 49 dB/km.

b. If coaxial cable is used in a digital system, the maximum pulse rate will vary approximately as the inverse of the square of the line length. Experiments with a 29-meter length of RG8/U cable by Wigington and Nahman (1957) suggest that for the 29-meter length, more than 4 G pulses/sec can be supported. One kilometer multimode fibers available today are capable of more than 100 m pulses/sec, as has been demonstrated in the laboratory (Gambling et al., 1971; Khan, 1972; Gambling et al., 1972; Gloge et al., 1972). For these fibers, the maximum pulse rate varies inversely as the length of the line (rather than $1/\ell^2$ as with the coaxial cable). Singlemode fibers would support more than 1G pulse/sec, and the pulse rate varies as the reciprocal of the square root of fiber length (as $1/\sqrt{\ell}$) (Gloge, 1971a, b). However, single-mode fibers would require rather complex equipment, including lasers and modulators. The multi-mode fibers will utilize cheaper and simpler emitters and modulators.

7. Components.

It is appropriate to give a brief summation of the terminal equipment which would be required in a future fiber link. Systems are not discussed.

a. Coherent sources.

The gas laser is undoubtedly the most common type of laser. It has often been mentioned as having possible application in optical-frequency communications. It is quite monochromatic, stable, and has good directional characteristics. It is less powerful than the solid-state counterparts. It requires 5 to 10 Watts of excitation power and produces 0.5 to 50 mW of laser power. It is inexpensive and several manufacturers supply self-contained units for less than $200. The frequency range is convenient both for fiber material and photodetector utility. The He-Ne gas laser is undoubtedly the smallest, cheapest, most reliable, and most rugged of the gas lasers, but it suffers the disadvantage of requiring a separate component to perform the modulation. For this purpose, electro-optical modulators utilizing anisotropic crystals are likely to be the most useful. Operating continuously at room temperature, the injection laser has shown much promise as a source for small signal applications. It is small, can be fabricated using fairly standard techniques, and, most important, it can be modulated directly without the use of inefficient electro-optic crystals. Depending on the use, it is felt that 100 mW would be a sufficient power level for many teleservice links.

The Ga-As injection laser could be the needed link in developing a source and the repeater for use with optical fibers in the longer trunk lines. Work is progressing on the development of optical integrated circuits and these will likely form the basis of an optical repeater.

b. Another form of light source, closely related to the Ga-As injection laser, is the light-emitting diode (LED). The only essential difference between Ga-As lasers and LED's regarding the spectral output is the line width. Under carefully controlled laboratory conditions, the laser linewidth can be tens of MHz, although for practical purposes it is greater. The typical LED linewidth is several hundred angstroms. This increased linewidth leads to decreased communication capability, as discussed earlier in this report.

The capability of a system is further reduced by virtue of the large radiation cone of the LED. This leads to the excitation of many modes in the fiber, as already discussed. An injection laser has a cone of emission of about 5° x 20°, while the LED usually radiates into a full 180°.

c. Detector.

There is a wide selection of detectors available, and correspondingly, a diversity of cost and performance tradeoffs. Response times available are quite adequate, at least for the immediate future, and it is not felt that the detector will be a limiting factor in finally specifying a workable system.

7. PERFORMANCE STANDARDS AND TESTS FOR THE DELIVERY SYSTEM

7.1 The FCC Report and Order

On February 12, 1972, the Federal Communications Commission (FCC) issued a CATV Report and Order which gave a complete set of instructions and rules for CATV operators. In Subpart K (Technical Standards), they listed requirements which relate to the performance of the CATV system as measured at matched subscriber terminals. Under these rules, it is incumbent upon the operator to make measurements on his system such that adequate performance is, in fact, insured. Subpart K of the Report and Order is given in its entirety in Appendix II.

Cable systems in operation prior to March 31, 1972, have until March 31, 1977, to comply; systems commencing operation on or after March 31, 1972, must comply with the rules immediately. The operator must conduct performance tests at least once each year (at intervals not to exceed 14 months), and the operator must maintain records pertaining to the tests for at least five years. The FCC requires that the measurements be made at no less than three widely separated points, at least one of which is representative of terminals most distant, in cable miles, from the input.

In examining Subpart K, we note that many of the specifications are determined by conditions at the output of the head-end. Other specifications can be met only if the distribution system is sufficiently good. Still other performance criteria depend upon both the head-end and the distribution system. These facts are summarized in Table 8, which lists the specifications and the cable system component which most affects the criterion (Best, 1972). The numbers in the first column of the Table refer to the FCC Technical Standard (para. 76.605).

Because the head-end plays such an important part in the system performance, it is logical to use the output from the head-end as one of the measurement points. Indeed, in some

TABLE 8

FCC Technical Specifications and Related Components

FCC No.	Technical Specification	Comments
2	Frequency of visual carrier must be 1.25 ± 25 kHz above lower boundary of CATV channel.	Affected only by head-end (converters, if any, and modulation).
2	Frequency of visual carrier at output of set-top converter must be 1.25 MHz ± 250 kHz above the lower frequency boundary of the CATV channel.	Head-end only indirectly affects this requirement.
3	Frequency of aural carrier must be 4.5 MHz ± 1 kHz above visual carrier of the same channel.	Affected by modulators at the head-end.
4	Visual signal level must be at least as follows: 1 millivolt for 75 Ω internal impedance; 2 millivolt for 300 Ω internal impedance; $\sqrt{0.0133\ Z}$ millivolt for Z Ω internal impedance.	Determined by both the head-end and the distribution system. The head-end will affect individual channels, whereas the distribution system effects are on multiple channels.
5	Maximum visual signal level variation on each channel shall be no greater than 12 dB.	Determined by both the head-end and the distribution system. The head-end will affect individual channels, whereas the distribution system effects are on multiple channels.
5(i)	3 dB maximum visual signal level variation between any two adjacent channels where the visual carriers are 6 MHz apart.	Determined primarily by head-end. Distribution system could affect conformation through a series of components having similar or related defects.
5(ii)	12 dB maximum visual signal level between any two visual carriers on the cable system.	Affected by both the head-end and the distribution system.

Table 8 (Continued)

FCC No.	Technical Specification	Comments
5(iii)	Maximum visual signal level at subscriber terminals shall be below threshold of degradation due to overload in subscriber's TV set.	Head-end would affect individual channels; distribution system is more likely to affect several (or all) channels.
6	Aural signal level must be 13 to 17 dB below associated visual signal level.	Determined primarily by head-end. Distribution system could affect conformation through a series of components having similar or related defects.
7	The peak-to-peak variation in visual signal level caused by low frequency disturbances shall not exceed 5% of the visual signal level.	Affected by either or both head-end and the distribution system. Low frequency response is determined by head-end, but the distribution system would be subject to various disturbances affecting conformation. Active devices in the head-end can cause hum or repetitive transients.
8	Channel frequency response shall be within ±2 dB for frequencies for frequencies within -1 MHz and +4 MHz of the visual carrier frequency.	Determined primarily by head-end. Distribution system could affect conformation through a series of components having similar or related defects.
9	The minimum signal-to-noise level or signal to properly offset co-channel signal ratio for all signals picked up or delivered within its Grade B contour shall be 36 dB.	Affected by both the head-end and the components in the distribution system.
10	Minimum signal to intermodulation on other non-offset carrier ratio shall be 46 dB.	Affected by both the head-end and the components in the distribution system.

Table 8 (Continued)

FCC No.	Technical Specification	Comments
11	Subscriber terminal isolation shall be at least 18 dB and sufficient to prevent visual picture impairments at any other subscriber terminal.	Affected entirely by the distribution system. Head-end has no effect.
12	Radiation from a cable system shall be no more than: 15 µV/m at 100' for frequencies to 54 MHz; 20 µV/m at 10' for frequencies 54-216 MHz; 15 µV/m at 100' for frequencies over 216 MHz.	Radiation can emanate from either the head-end or the distribution system. Cable connectors are potential problem components.

cases, the characteristics of the head-end alone determine compliance. Thus, first and foremost, the head-end must be capable of meeting the FCC specifications. If it does not, the other measurements in the field will have little meaning.

The FCC undoubtedly intended that the quality of the signal delivered to the home should be above some minimum. The means to that end are in the specifications discussed above. Of course, meeting the technical specifications at three widely separated points does not guarantee that all subscribers on the system will receive good quality pictures. It does guarantee the capability of the system, however.

A question naturally arises as to the adequacy of these means to the desired end. Judgment of picture quality is quite subjective and therefore potentially controversial. Added to this is the fact that the only known thorough study of picture quality was made before the FCC technical specifications came into being (Town, 1960; Dean, 1960; see also the subsequent discussion on the TASO results in this report). Thus, there are no alternative relationships between picture quality and the FCC specifications. This is needed as the next step in evolving complete standards for performance.

In Section 7.4, the FCC requirements, measurements relating to proof of performance, and recommendations of other cable television agencies are outlined.

7.2 The TASO Study

As a result of a request made by the Federal Communications Commission, there was formed in 1956 a Television Allocations Study Organization (TASO) under the direction of George R. Town. The Study Organization was formed by the television industry for the purpose of developing "full, detailed and reliable technical information, and engineering principles based thereon, concerning present and potential VHF and UHF television service." The problems assigned to TASO were wide in scope but basically evolved from a frequency allocation dilemma. Thus, six panels were formed to consider subtasks associated with the allocations problems:

Panel 1: Transmitting equipment.
Panel 2: Receiving equipment.
Panel 3: Field tests.
Panel 4: Propagation data.
Panel 5: Analysis and theory.
Panel 6: Levels of picture quality.

The final TASO report was entitled "Engineering Aspects of Television Allocations," dated March 16, 1959. The results of the study are summarized in a Special Issue of the Proceedings of the IRE, Vol. 48, No. 6, June 1960.

The report is, of course, quite old and deals mostly with problems of that day. The report contains considerable information, however, which is referred to often, even today. The results of the work of Panel 6, for example, are applicable today and, in fact, represent a basis for standards in picture quality. The subjective picture quality, as judged by representative groups of observers drawn from the general public, was related to technical picture impairment due to controlled amounts of interferences of different types. Personnel skilled in the design, conduct, and interpretation of psychological testing conducted the survey. Picture quality was rated on a six-point scale: 1. Excellent, 2. Fine, 3. Passable, 4. Marginal, 5. Inferior, 6. Unusable.

Picture impairment was due to thermal noise, co-channel interference (with various carrier frequency offsets), and adjacent-channel interference (upper and lower), as well as certain combinations of these. Both color and monochrome receivers of upper-middle-grade quality were used. A variety of still pictures were used in the tests. Checks were used and indicated that the results were consistent and reliable. The results of the measurement program involving almost 200 observers are presented by Dean (1960).

Representative values of level of impairment resulting in a grade 3 (passable) picture are given in the accompanying table (from Town, 1960).

Table 9

Level of Interference for "Passable"

(Grade 3 on 6-Point Scale) Picture

Interference	Average Ratio Desired-to-Undesired Signal (dB) for "Passable" Picture
Thermal Noise	27
Co-channel, 360-Hz carrier offset	22
Co-channel, 604-Hz carrier offset	41
Co-channel, 9985-Hz carrier offset	22
Co-channel, 10010-Hz carrier offset	18
Co-channel, 19995-Hz carrier offset	26
Co-channel, 20020-Hz carrier offset	18
Lower Adjacent Channel	-26
Upper Adjacent Channel	-27

Picture quality is a very subjective aspect, as can be seen from Fig. 33. This figure is based on FCC Report TRR 5.1.2, April 1, 1960 (cf. O'Connor, 1968). It shows the required signal-to-noise ratio (random noise) in dB for picture quality grades 1-5 on the 6-grade scale. We note that the least discriminating 10% of the viewers would note a picture passable when signal-to-noise ratio is only 22 dB. The most discriminating viewer requires 34 dB to rate the picture passable. Clearly the relationship between signal level, noise level, and picture quality will be difficult to interpret in terms of widely accepted standards.

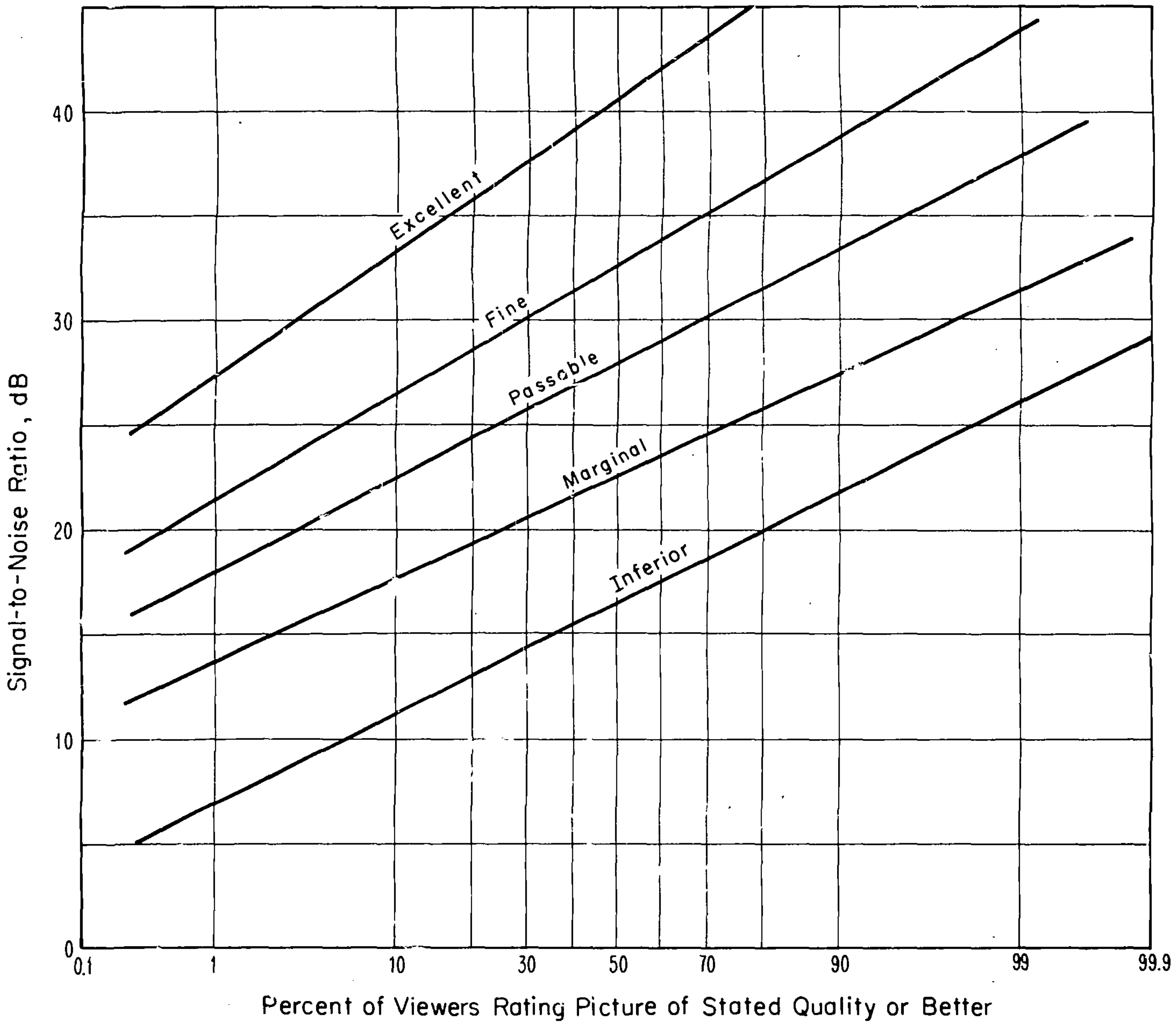


Figure 33. Picture Quality Ratings. (Courtesy IEEE; from Town, 1960.)

.3 NCTA Standards

At least two important standards have been prepared by the NCTA and others will be added. An amendment entitled "CATV Amplifier Distortion Characteristics" (NCTA-002-0267) has been adopted to replace the Proposed NCTA Standard on Output Capability of CATV Amplifiers published by the NCTA on October 28, 1966. As the result of a study by the NCTA Standards Committee and the Engineering Subcommittee, they decided that a standard for amplifier "output capability" was impractical. The Proposed Standard was deficient in distinguishing between cross-modulation, second-order beats, and other spurious frequency products resulting from amplifier nonlinearity. The Committee determined that, for several reasons, the concept of "output capability" appeared to be obsolete and that the NCTA Standard should, therefore, describe methods for measuring and specifying amplifier distortion under conditions as close as practicable to actual recommended operating practices.

The NCTA Standard alluded to here (NCTA-002-0267) recognizes two forms of distortion as acting to limit the useful output of a CATV amplifier: cross-modulation and spurious signals. Cross-modulation is measured with all visual carriers synchronously modulated with a symmetrical 15.75-KHz square wave and a CW reference signal of equal amplitude on the desired channel. In order to test amplifiers at the recommended operating level, the test equipment must be capable of measuring about 90 dB down from the carrier level.

The spurious signal ratio is the ratio of the amplitude of the strongest spurious signal, within the limits of 1 MHz below and 4.2 MHz above the visual carrier frequency, to the amplitude of that visual carrier. A spectrum analyzer having a high order of selectivity is required to detect the spurious signals which fall close to the carrier frequency, as most do.

The NCTA Standards Committee also specified methods of measuring noise levels in head-ends, amplifier cascades, etc. They also discussed the calibration necessary for accurate noise level measurement (NCTA-005-0669, Noise Level in Cable Systems). The method uses a "standard" amplifier of known noise figure and gain to determine the characteristics of the signal level meter used for system noise level measurements.

While these NCTA Standards do much to describe degradation of cable systems due to noise and distortion in the components, the quality of the picture depends on other factors, some of them not even a part of the cable system. The studio equipment and the subscriber terminal equipment, for example, are two very important components which could degrade the picture quality even in the absence of noise and/or distortion due to system components. In addition, the head-end is composed of combinations of various pieces of electronic components. The system performance depends critically on how the various components are combined to form a system. It is therefore not sufficient to guarantee the performance of components; one must examine and test the performance of the assemblage which constitutes the head-end.

7.4 FCC Requirements and Other Recommendations

In this section, the technical requirements and measurement procedures for CATV systems are reviewed and examined. Comments are offered toward upgrading the picture quality at the subscriber's terminal by the examination of the frequency tolerances, signal-to-noise ratios, intermodulation, subscriber's terminal isolation, radiation, and reflections on the system. The existing FCC Technical standards do not provide performance requirements for such things as differential gain, differential phase, or envelope delay. These are important factors in color television transmission.

In the following, reference will be made by number to the FCC Rules and Regulations.

The visual frequency should be 1.25 MHz above the lower boundary and have a variation of ± 25 kHz, according to 76.605(2). Gumm (1972) endorses this standard. However, this standard is not consistent with 73.668 of the Television Broadcast Stations, Rules and Regulations, which has a smaller tolerance of ± 1000 Hz for the carrier frequency. The difference between ± 25 kHz and ± 1 kHz is substantial and should be investigated.

It may be that the more stringent tolerance of ± 1 kHz cannot be met by today's CATV systems. In any case, one is led to wonder why these tolerances are not consistent.

Under FCC 76.605 (3) the frequency of the aural carrier shall be 4.5 MHz ± 1 kHz above the frequency of the visual carrier. This separation tolerance is identical to 73.668 (b) for the Television Broadcast Stations Rules and Regulations. The standard is within the state of the art and needs no further explanation or investigation at this time. The third and final frequency standard pertains to the FM sound carrier. Gumm (1972) suggests an engineering standard which is the same as FCC 73.269 for FM broadcasters. This allows variation of ± 2 kHz for the sound carrier and appears in keeping with the video carrier standard in 73.668. Effort should be made to set new standards compatible with existing broadcaster's standards.

The method of making frequency measurements for television signals is usually left to the licensee FCC 73.690 (Vol. III, 1972). Tests can easily be made with modern test equipment. One suggested method uses electronic digital counters which are the most convenient, versatile, and accurate instruments available for making frequency measurements (Hale et al., 1972).

A 12-dB maximum RF signal variation between any two visual carriers is permitted in a 24-hour period, according to the FCC's 76.605(5). Gumm (1972) has suggested that the permitted variation be lowered to 7 dB.

The measurement procedure suggested by Hale et al. (1972) appears to be inadequate for long-term recordings. The problem of obtaining and analyzing the signal levels needs further attention.

The maximum peak-to-peak variation in visual signal level caused by hum, inadequate low-frequency response, or other repetitive transients is given by paragraph (7) of FCC 76.605 as being 5% or less. This implies a ripple or modulation riding on the video carrier, which can be difficult to measure because of the close spacing of the modulation sidebands (Hale et al., 1972). A relationship between the 5% and its equivalent in the more common measurement term (decibels) needs to be examined.

According to the FCC's 76.605(9), the minimum visual carrier-to-noise ratio shall be 36 dB in a 4-MHz bandwidth of noise. The results of the TASO studies (see Fig. 33) show the subjective evaluation of picture quality as a function of signal-to-noise ratio, based on random noise.

From Fig. 33 , these conclusions are seen when the signal-to-noise ratio is 36 dB:

93% of the viewers considered the picture passable;
72% of the viewers considered the picture fine;
20% of the viewers considered the picture excellent.

A desired engineering standard (Gumm, 1972) proposes an increase in the minimum signal-to-noise ratio to 40 dB. This is in keeping with the Federal Communications Commission's paramount concern to recognize that the end product is the television signal delivered to the subscriber (Lines, 1972). If 40 dB is used as a minimum signal-to-noise ratio, then a higher percentage of viewers will have fine or excellent picture quality. From Fig. 33, 92% will rate the picture as fine and 40% as excellent.

The Electronics Industries Association (EIA) recommends a weighted signal-to-noise ratio of 33 dB as the "outage threshold" beyond which the noise will be unacceptable (RS-250A, 1967). An uncertainty is the relationship between random noise and weighted noise, and therefore little can be concluded from the EIA figure and the TASO graph. For color threshold, the EIA requires 37 dB as the signal-to-noise ratio. The FCC does not distinguish between color and black and white in its signal-to-noise ratio of 36 dB. The TASO data were published over twelve years ago and should be updated, with special emphasis on color reception.

In CCIR Recommendation 421-2 (CCIR, Vol. V, 1970) for the requirements for the transmission of television signals over long distance, the signal-to-noise ratio for a single frequency between 1 kHz and 1 MHz is given as 59 dB. The signal-to-noise ratio decreases linearly to 43 dB between 1 MHz and the cutoff of frequency at a single frequency. Similar consideration should be given to the specifications of head-end and other feed points of a CATV system before signals enter the cable for distribution.

The oscilloscope method of measurement for the signal-to-noise ratio (Hale et al., 1972) and the selective voltmeter or field strength technique (Taylor, 1970) are both acceptable. A question arises over the interchange of the terms "carrier-to-noise ratio" (Taylor, 1970) and "signal-to-noise ratio" (FCC, 1972). The two terms have been used a great deal but their relationship is not clear. In the more common FM systems, the two are not equal but are related by the receiver transfer function, which is dependent upon a number of factors such as deviation ratio, bandwidth, noise figure, etc. A suitable transfer relation needs to be obtained between carrier to noise at the input of a television receiver and the output video signal-to-noise ratio.

A desired engineering standard proposed by Gumm (1972) is more stringent than the FCC Standard 76.605 (10), which specifies the permitted level of coherent disturbance with respect to visual signal level.

The methods for intermodulation (Taylor, 1966; Hale et al., 1972) are conventional approaches; however, newer techniques should be examined. As an example, the noise power ratio (NPR) measuring technique CCITT, (1968) should be investigated because it sums all of the intermodulation products and relates the sum to a meaningful performance figure.

In the FCC's 76.605 (11), the subscriber's isolation is specified as only 18 dB, while a desired engineering standard expects 30 dB (Gumm, 1972). At the present, little is understood of what isolation figures mean in terms of performance or picture quality. The action of the automatic gain control (AGC) needs to be considered for the measurement of isolation to be meaningful because of the importance of having an adjacent-channel signal present. The suggested measurement procedure by Hale et al. (1972) does not present a realistic figure because it lacks a television signal on the adjacent channel. Without an RF signal, the receiver uses maximum gain, which will not occur in actual operation because of the FCC's 76.605 (9) required minimum signal-to-noise ratio of 36 dB.

The relation between CATV frequencies and radiation limits versus distance from the source is given in FCC's

76.605 (12). While classified as general requirements and referenced (Subpart D, 15.161), they should also include the lower requirements for sparsely inhabited areas (FCC, 1972). The difference between the levels could allow systems which are marginal or questionable to be within the specifications.

A difficulty has developed in separating the directly-picked-up RF signal and the signal leaking from the cable (Communication News, 1972). Further investigation of useful methods is required to resolve the measurement problem, beginning with the possibility of adding carefully selected CW signals to the system. Hopefully, unambiguous readings can be obtained by the insertion of known signals.

The recommended method for radiation measurements (Hale et al., 1972) uses a spectrum analyzer as both the receiver and display units, while the FCC measurement procedure (FCC, Vol. II, 1972) specifies a field strength meter. The report by CCIR shows difficulty in reaching a complete international standardization for the spurious emission of equipment in the 25- to 500-MHz frequency range. The CCIR has extended an invitation for proposed methods of measuring spurious emission parameters.

The chrominance subcarrier frequency for television broadcasters should be 3.579545 MHz with a variation of ± 10 Hz with a maximum rate of change not to exceed one-tenth

Hertz per second (FCC, 73.682). Before applying this standard to CATV, operational systems should be studied to determine the current variation of the subcarrier frequency and the amount of performance improvement that can be expected by tightening the standard.

The perceptible level of television signal reflections (Page, 1969), is reproduced in Fig. 5 and relates the attenuation level to time delay. A level of reflection 40 dB below the signal is required for delays greater than 0.4 microsecond. It is not known if this is only for monochrome television signals and what changes are required for color reception. A minimum of 40 dB is also recommended for the desired engineering standard for the reflections within a system (Gumm, 1972). A conflicting value is given by the CCIR (Vol. V, 1970), which is for the re-radiation from masts in the neighborhood of transmitting antennas. It gives 32 dB as the ratio for negligible impairment between direct and re-radiated signals. Further investigation is needed to resolve the 8-dB difference.

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APPENDIX I

Definition of Terms

There is sometimes disagreement on definition of technical terms. We include in this appendix a list of common terms and their definitions. Unless otherwise noted, these definitions are used throughout this report.

AGC (AUTOMATIC GAIN CONTROL): A circuit for automatically controlling amplifier gain in order to maintain a constant output voltage with a varying input voltage within a predetermined range of input-to-output variation.

AMPLIFIER: A device whose output is essentially an enlarged reproduction of the input without drawing power from the input.

AMPLIFIER (ALL-CHANNEL CATV): A very broadband amplifier which will pass and amplify all VHF television channels and the FM broadband channels.

AMPLIFIER (CATV MAIN LINE): A pole-mounted or messenger-suspended weatherproof amplifier designed for insertion at intervals in a coaxial CATV feeder cable.

Provides about 25 dB gain over the band 50-220 MHz, and is powered by low-voltage, 60-Hz ac fed over the coaxial cable.

AMPLIFIER (HETERODYNE CATV): A single-channel TV amplifier which does not demodulate the television signal, but instead, down-converts it to an intermediate frequency (IF), amplifies it at IF, then up-converts it to the original channel.

AMPLITUDE MODULATION (AM): A system of modulation in which the envelope of the transmitted wave contains a component similar to the wave form of the signal to be transmitted.

APL (AVERAGE PICTURE LEVEL): The average signal level during active scanning time, i.e., excluding intervals at blanking and sync, integrated over a frame period. It is expressed as a percentage of the blanking-to-reference white range.

ASPECT RATIO: The ratio of width to height for the frame of the televised picture; four units wide by three units high in standard systems.

ATTENUATION: In general terms, a reduction in signal strength.

ATTENUATOR: A network to reduce signal strength by a known amount. Usually expressed in dB.

AUDIO FREQUENCY: Any frequency corresponding to a normally audible sound wave. Roughly from 15 to 20,000 Hz per second.

AURAL CENTER FREQUENCY: (1) The average frequency of the emitted wave when modulated by a sinusoidal signal; (2) the frequency of the emitted wave without modulation.

AUTOMATIC TILT: Automatic correction of changes in tilt.

BACK PORCH: That portion of the composite picture signal which lies between the trailing edge of the horizontal sync pulse and the trailing edge of the corresponding blanking pulse.

BANDPASS: A specific range of frequencies that will be passed through a device.

BANDPASS FILTER: A filter that will pass only a specific band of frequencies.

BANDPASS FLATNESS: The gain variations in the bandpass frequencies of a device.

BANDWIDTH: The number of cycles per second expressing the difference between the lower and upper limiting frequencies of a frequency band; also, the width of a band of frequencies.

BARREL DISTORTION: Distortion that causes the televised image to appear to bulge outward on all sides like a barrel.

BLACK LEVEL: The level of a television picture signal that corresponds to the maximum limits of the black component of the picture.

BLANKING: The process of cutting off the electron beam in a camera or picture tube during the retrace period.

BLANKING LEVEL: The level of a composite picture signal which separates the range containing picture information from the range containing synchronizing information; also called pedestal, or "blacker than black."

BLANKING SIGNAL: A signal composed of recurrent pulses, related in time to the scanning process, and used to effect blanking.

BLOCK TILT: A form of half-tilt where groups of channels are set to a common level, e.g., low-band channels are set at the same level as Channel 2, and all high-band channels to the same level as Channel 13.

BREEZEWAY: In NTSC color, that portion of the back porch between the trailing edge of the horizontal synchronizing pulse and the start of the color burst.

BRIDGING AMPLIFIER OR BRIDGER: An amplifier which is connected directly into the main trunk of a CATV system. It serves as a high-quality tap, providing isolation between the main trunk and multiple high-level outputs.

CABLE COUPLER: A device to join lengths of cable having the same electrical characteristics.

CABLE POWERING: A method of supplying power to solid-state CATV equipment by utilizing the coaxial cable to carry both signal and power simultaneously.

CAMERA CHAIN: The television camera, associated control units, power supplies, monitor, and connecting cables.

CAMERA TUBE: An electron tube that converts an optical image into an electrical current by a scanning process. Also called a pickup tube.

CASCADE AMPLIFICATION: High-gain, low-noise amplification with a high-impedance input.

CATV: Common abbreviation for Community Antenna Television.

CCTV: Common abbreviation for Closed Circuit Television.

CHANNEL STRIP: A device having a bandpass sufficient to amplify one television channel. Also called single-channel amplifier.

CHROMINANCE: The colorimetric difference between any color and a reference color of equal luminance, the reference color having a specific chromaticity.

CHROMINANCE SIGNAL: That portion of the NTSC color television signal which contains the color information.

CLAMPER: A device which functions during the horizontal blanking or synchronizing interval to fix the level of the picture signal at some predetermined reference level at the beginning of each scanning line.

CLAMPING: The process that establishes a fixed level for the picture level at the beginning of each scanning line.

CLIPPING: The limiting of the peaks of a signal. For a picture signal, this may affect either the positive (white) or negative (black) peaks. For a composite video signal, the synchronizing signal may be affected.

COGWHEEL: Horizontal displacement of alternate scan lines of the order of 1 microsecond. Results in a gear-tooth-like appearance of vertical and diagonal lines within a given scene.

COLOR BURST: That portion of the composite color signal, comprising a few cycles of a sine wave of chrominance subcarrier frequency, which is used to establish a reference for demodulating the chrominance signal. Normally approximately 9 cycles of 3.58-MHz subcarrier on the back porch of the composite video signal.

COLOR CONTAMINATION: An error of color rendition due to incomplete separation of paths carrying different color components of the picture.

COLOR SUBCARRIER: In NTSC color, the 3.58-MHz carrier whose modulation sidebands are added to the monochrome signal to convey color information.

COLOR SYNC SIGNAL: A signal used to establish and to maintain the color relationships that are transmitted.

COLOR TRANSMISSION: The transmission of a signal which represents both the brightness values and the color values in a picture.

COMBINING NETWORK: A passive network which permits the addition of several signals into one combined output with a high degree of isolation between individual inputs.

COMPOSITE COLOR SYNC: The signal comprising all the color signals necessary for proper operation of a color receiver. This includes the deflection sync signals to which the color sync signal is added in the proper time relationship.

COMPOSITE PICTURE SIGNAL: The signal which results from combining a blanked picture signal with the synchronizing signal.

COMPOSITE VIDEO SIGNAL: The combined picture signal, including vertical and horizontal blanking and synchronizing signals.

COMPRESSION: The reduction in gain at one level of a picture signal with respect to the gain at another level of the same signal.

CONTRAST: The range of light and dark values in a picture or the ratio between the maximum and minimum brightness values.

CONTRAST RANGE: The ratio between the whitest and blackest portions of a television image.

CONVERTER: A device to convert one or more television channels to one or more other channels.

COUNTERMODULATION: A type of cross-modulation distortion. Interfering modulation appears as out-of-phase modulation of the desired signal. "White Windshield Wiping" is typical countermodulation. May be caused by a combination of second-order distortions.

CROSS MODULATION (CROSS TALK): A form of distortion where modulation of an interfering station appears as a modulation of the desired station. Caused by third- and higher-odd-order nonlinearities. A typical example of cross modulation is the form of overload known as "windshield wiping."

CUTOFF FREQUENCY: That frequency beyond which no appreciable energy is transmitted. It may refer to either an upper or lower limit of a frequency band.

dB (DECIBEL): Basically, a measure of the power ratio between two signals. In system use, a measure of the voltage ratio of two signals, provided they are measured across a common impedance.

DC RESTORER: A device for re-establishing by a sampling process the dc and the low-frequency com nents of a video signal which have been suppressed by ac transmission.

DC RESTORATION: The re-establishment by a sampling process of the dc and the low-frequency components of a video signal which have been suppressed by frequency.

DC TRANSMISSION: A form of transmission in which the dc components of the video signal are transmitted.

DELAY DISTORTION: Distortion resulting from the non-uniform speed of transmission of the various frequency components of a signal; the various frequency components of the signal have different times of travel (delay) between the input and the output of a circuit.

DETAIL CONTRAST: The ratio of the amplitude of the video signal representing the high-frequency component with the amplitude representing the reference low-frequency component; usually expressed as a percentage at a given line number.

DIFFERENTIAL GAIN: In a video transmission system, the difference in the gain of the system in decibels for a small high-frequency sinewave signal at two stated levels of a low-frequency signal on which it is superimposed.

DIFFERENTIAL PHASE: In a video transmission system, the difference in phase shift through the system for a small high-frequency sinewave signal at two stated levels of a low-frequency signal on which it is superimposed.

DIRECTIONAL COUPLER: A device having one input and providing two or more isolated outputs for rf cable runs.

DISPLACEMENT OF PORCHES: A term referring to any difference between the level of the front porch and the level of the back porch during the horizontal synchronizing level.

DISTORTION: The deviation of the received signal waveform from that of the original transmitted waveform.

DISTRIBUTION SYSTEM: The part of a CATV system used to carry signals from the head-end to subscribers' receivers. Often applied, more narrowly, to the part of a CATV system starting at the bridger amplifiers.

ECHO: A signal which has been reflected at one or more points during transmission with sufficient magnitude and time delay as to be detected as a signal distinct from that of the primary signal. Echoes can be either leading or lagging the primary signal and appear as reflection, or "ghosts."

EQUALIZATION: The process of correcting loss-frequency and delay-frequency characteristics of a signal to be within overall system objectives. Usually applied at the receiving terminal in order to minimize the possibility of excessive noise being introduced as a result of low signal levels.

EQUALIZER: Equipment designed to compensate for loss and delay frequency effects within a television system.

EQUALIZING PULSES: Pulses at twice the line frequency.

ETV: The common abbreviation for Educational TV.

EXPANSION: An undesired increase in the amplitude of a portion of the composite video signal relative to another portion. Also, a greater than proportional change in the output of a circuit for a change in input level. Opposite of compression.

FADER: A control or group of controls for effecting fade-in and fade-out of video or audio signals.

FEEDER LINE: The coaxial cable running between bridgers, line extenders, and taps.

FIELD: One of the two equal parts into which a television frame is divided in an interlaced system of scanning.

FIELD FREQUENCY: The number of fields transmitted per second in a television system. The U.S. standard is 60 fields per second. Also called field-repetition rate.

FLAT LOSS: Equal loss at all frequencies, such as that caused by attenuators.

FLAT OUTPUTS: Operation of a CATV system with all channels at equal levels at the output of each amplifier, corresponding to fully-tilted input signals.

FLYBACK: The rapid return of the electron beam in the direction opposite to that used for scanning.

FRAME: The total picture area which is scanned while the picture signal is not blanked.

FREE-RUNNING FREQUENCY: The frequency at which a normally synchronized oscillator operates in the absence of a synchronizing signal.

FREE-SPACE FIELD INTENSITY: The field intensity that would exist at a point in the absence of waves reflected from the earth or other objects

FREQUENCY MODULATION (FM): A system of modulation where the instantaneous radio frequency varies in proportion to the instantaneous amplitude of the modulating signal (amplitude of modulating signal to be measured after pre-emphasis, if used), and the instantaneous radio frequency is independent of the frequency of the modulating signal.

FREQUENCY RESPONSE: The range or band of frequencies over which a device will offer essentially the constant characteristics.

FREQUENCY SWING: The maximum departure of the frequency of the emitted wave from the center frequency resulting from modulation.

FRONT PORCH: That portion of the composite picture signal which lies between the leading edge of the horizontal blanking pulse and the leading edge of the corresponding synchronizing pulse.

FULL-TILT: Operation of a CATV system with maximum tilt at the output of each amplifier (flat input signals at each amplifier).

GAIN: A measure of amplification, usually expressed in dB. For matched CATV components, power gain is readily determined as insertion power gain. Gain of an amplifier is often specified at the highest frequency of operation, for example, at 260 MHz for all-band equipment.

GAIN-FREQUENCY DISTORTION: Distortion which results when all of the frequency components of a signal are not transmitted with the same gain.

GEOMETRIC DISTORTION: An aberration which causes the reproduced picture to be geometrically dissimilar to the perspective plane projection of the original scene.

GHOST: A shadowy or weak image in the received picture, offset either to the right or to the left of the primary image, the result of transmission conditions which create secondary signals that are received earlier or later than the main, or primary, signal. A ghost displaced to the left of the primary image is designated as "leading," and one displaced to the right is designated as "following" (lagging). When the tonal variations of the ghost are the same as those of the primary image, it is designated as "positive" and when the opposite condition occurs, it is designated as "negative."

GLITCHES: A form of low-frequency interference appearing as a narrow horizontal bar which is either stationary or moving vertically through the picture. This is also observed on an oscilloscope at the field or frame rate as an extraneous voltage pip in the signal at approximately the reference black level.

HARMONIC: A signal having a frequency which is an integral multiple of the fundamental frequency to which it is related.

HALF-TILT: Operation of a CATV system half way between full-tilt and flat-output operation. Compared with a FULL-TILT system, the level of Channel 2 is up at the input and output of an amplifier by one-half the slope of the amplifier.

HEAD-END: The electronic equipment located at the start of a cable system, usually including antennas, preamplifiers, frequency converters, demodulators, modulators, and related equipment.

HI-BAND: The high VHF television channels, 7 through 13.

HIGH-FREQUENCY DISTORTION: Distortion effects which occur at high frequency. In television, generally considered as any frequency above the 15.75-KHz line frequency.

HIGHLIGHTS: The maximum brightness of the picture, which occurs in regions of highest illumination.

HORIZONTAL (HUM) BARS: Relatively broad horizontal bars, alternately black and white, which extend over the entire picture. They may be stationary or may move up and down. Sometimes referred to as a "venetian blind" effect, it is usually caused by a 60-Hz interfering frequency or a harmonic frequency thereof.

HORIZONTAL BLANKING: The blanking signal at the end of each scanning line.

HORIZONTAL RESOLUTION: The maximum number of individual picture elements that can be distinguished in a single horizontal scanning line. Also called horizontal definition.

HORIZONTAL RETRACE: The return of the electron beam from the right to the left side of the raster after the scanning of one line while the screen is blanked or cut off.

HUE: Color, or tint, such as red, blue, etc.

HUM: A low-pitched droning noise, consisting of several harmonically related frequencies, resulting from an alternating-current power supply or from induction due to exposure to a power system. (Note: By extension, the term is applied in visual systems to interference from similar sources.)

HUM MODULATION: Modulation of a radio frequency or detected signal by hum.

IMPEDANCE (INPUT OR OUTPUT): The input or output characteristic of a system component that determines the type of transmission cable to be used. The cables used must have the same characteristic impedance as the component. Expressed in ohms. Video distribution has been standardized for 75-ohm coaxial and 124-ohm balanced cable.

INLINE PACKAGE: A housing for amplifiers or other CATV components designed for use without jumper cables; cable connectors on the ends of the housing are in line with the coaxial cable.

INSERTION LOSS: Additional loss in a system when a device such as a directional coupler is inserted; equal to the difference in signal level between input and output of such a device.

INTEGRATED SYSTEM: A term used to denote a system in which all components, including various types of amplifiers and taps, have been designed from a well founded overall engineering concept to be fully compatible with each other. Such a system results in greater economy at improved performance through the avoidance of over specification by well engineered design center values.

INTERFERENCE: Extraneous energy which tends to interfere with the reception of the desired signals.

INTERLACED SCANNING: A scanning process for reducing image flicker in which the distance from center to center of successively scanned lines is two or more times the nominal line width, and in which the adjacent lines belong to different fields.

INTERMODULATION: A form of distortion where two modulated or unmodulated carriers produce beats according to the frequency relationship $f = nf \pm mf$, where n and m are integers. Intermodulation is caused by second- and higher-order curvature, and is essential for the proper operation of frequency converters, mixers, modulators, and multipliers. Second-order curvature by itself does not cause distortion of the modulation envelope, but is often responsible for parasitics. The order of the intermodulation product is defined as n plus m.

ITV: Common abbreviation for Instructional Television.

JITTER: Small, rapid variations in a waveform due to mechanical disturbances or to changes in the characteristic of components, supply voltages, imperfect synchronizing signals, circuits, etc.

LEADING EDGE: The major portion of the rise of a pulse, taken from 10 to 90 percent of total amplitude.

LEVEL: Signal amplitude measured in accordance with specified techniques.

LEVEL DIAGRAM: A graphic diagram indicating the signal level at any point in a system.

LINE EXTENDER OR DISTRIBUTION AMPLIFIER: Amplifiers used in the feeder system.

LINE SPLITTER: A term given a device to provide two or more isolated branch cable runs from one cable run in RF distribution systems.

LOSS: A reduction in signal level or strength, usually expressed in dB.

LOW BAND: The low VHF television channels, 2 through 6.

LOW-FREQUENCY DISTORTION: Distortion effects which occur at low frequency. In television, generally considered as any frequency below the 15.75-KHz line frequency.

LUMINANCE: Luminous flux emitted, reflected, or transmitted per unit solid angle per unit projected area of the source.

LUMINANCE SIGNAL: That portion of the NTSC color television signal which contains the luminance or brightness information.

MAIN TRUNK: The major link from the head-end to a community or connecting communities.

MASTER ANTENNA TELEVISION SYSTEM: A combination of components providing multiple television receiver operation from one antenna or group of antennas, normally within a single building.

MATCHING: The effort to obtain like impedances at a transmission line junction to allow a reflection-free transfer of signal through the junction.

MATCHING TRANSFORMER: A device to transform signals from one impedance to another. In RF television systems, usually 75-ohm unbalanced to 300-ohm balanced.

MATV: Abbreviation for Master Antenna Television.

MICROPHONICS: Audio-frequency noise caused by the mechanical vibration of elements within a system or component.

MIXER: A device which combines audio, video, or RF signals while at the same time maintaining an impedance match.

MODULATION: The process, or results of the process, whereby some characteristic of one signal is varied in accordance with another signal. The modulated signal is called the carrier.

MONITOR: A device that displays on a picture tube the images detected and transmitted by a television camera.

MONITOR AMPLIFIER: A device for amplifying audio signals for the purpose of monitoring the signals fed to the distribution system.

MONOCHROME: Having only one chromaticity, usually achromatic. In television, black and white.

MONOCHROME SIGNAL: In monochrome television, a signal for controlling the brightness values in the picture. In color television, that part of the signal which has major control of the brightness values of the picture, whether displayed in color or in monochrome.

MONOCHROME TRANSMISSION (BLACK AND WHITE): The transmission of a signal which represents the brightness values in the picture, but not the color (chrominance) values.

MULTIPLEX TRANSMISSION (AURAL): A subchannel added to the regular aural carrier of a television broadcast station by means of frequency-modulated subcarriers.

NCTA: National Cable Television Association.

NEGATIVE IMAGE: A picture signal having a polarity which is opposite to normal polarity and which results in a picture in which the white and black areas are reversed.

NOISE: The word "noise" originated in audio practice and refers to random spurts of electrical energy or interference. In some cases, it will produce a "salt-and-pepper" pattern over the televised picture. Heavy noise is sometimes referred to as "snow."

NOISE FIGURE: A measure of the noisiness of an amplifier. Noise _factor_ is defined as the ratio of input signal-to-noise ratio to output signal-to-noise ratio. Noise _figure_ is noise factor expressed in dB. The lowest possible value for a matched system is 3 dB.

NTSC: National Television Systems Committee. A committee that worked with the FCC in formulating standards for the present-day United States color television system.

OVERLOAD-TO-NOISE RATIO: The ratio of overload-to-noise level measured at or referred to the same point in a system or amplifier, usually expressed in dB, and commonly used as an amplifier figure of merit. Not to be confused with signal-to-noise ratio.

OVERSHOOT: The initial transient response to a unidirectional change in input, which exceeds the steady-state response.

PAIRING: The overlapping of alternate scanning lines resulting in a severe reduction in vertical resolution.

PASSIVE: A circuit or network not using active devices such as tubes or transistors.

PEAK POWER: The power over a radio frequency cycle corresponding in amplitude to synchronizing peaks.

PEAK PULSE AMPLITUDE: The maximum absolute peak value of a pulse, excluding those portions considered to be unwanted, such as spikes.

PEAK-TO-PEAK: The amplitude (voltage) difference between the most positive and the most negative excursions (peaks) of an electrical signal.

PERCENTAGE MODULATION: As applied to frequency modulation, the ratio of the actual frequency swing to the frequency swing defined as 100 percent modulation, expressed in percentage. For the aural portion of television signals, a frequency swing of ± 25 kilocycles is defined as 100 percent modulation.

PICTURE MONITOR: Cathode-ray tube and associated circuitry arranged for viewing a television picture.

PIGEONS: Noise observed on picture monitors as pulses or bursts of short duration, at a slow rate of occurrence. A type of impulse noise.

POLARIZATION: The orientation of the electric field as radiated from the transmitting antenna.

PREAMPLIFIER: An amplifier, the main purpose of which is to increase the output of a low-level source such that the signal can be further processed without additional deterioration of the signal-to-noise ratio.

PRE-EMPHASIS: A change in the level of some frequency components of the signal with respect to the other frequency components at the input to a transmission system. The high-frequency portion of the signal is usually retransmitted at a higher level than the low-frequency components.

PULSE: A variation of a quantity whose value is normally constant; this variation is characterized by a rise and a decay, and has finite amplitude and duration.

PULSE RISE TIME: Time interval between upper and lower limits of instantaneous amplitude; specifically, 10 and 90 percent of the peak-pulse amplitude, unless otherwise stated.

RANDOM INTERLACE: A technique for scanning often used in closed-circuit television systems. This technique provides somewhat less precision than that obtained in commercial broadcast service.

REFERENCE BLACK LEVEL: The picture signal level corresponding to a specified maximum limit for black peaks.

REFERENCE WHITE LEVEL: The picture signal level corresponding to a specified maximum limit for white peaks.

REFLECTION COEFFICIENT: Ratio of magnitude of reflected wave to incident wave, mathematically related to VSWR.

RETURN LOSS: Reflection coefficient expressed in dB.

REPEATER: The equipment used for receiving, amplifying, and retransmitting a signal in a very long transmission line. It restores the signal to sufficient amplitude and correct shape to operate in the receiving equipment satisfactorily. Generally used in conjunction with a transmit terminal and a receive terminal.

RESOLUTION (HORIZONTAL): The amount of resolvable detail in the horizontal direction in a picture. It is usually expressed as the number of distinct vertical lines, alternately black and white, which can be seen at a distance equal to picture height.

RESOLUTION (VERTICAL): The amount of resolvable detail in the vertical direction in a picture. It is usually expressed as the number of distinct horizontal lines, alternately black and white, which can theoretically be seen in a picture.

RF (RADIO FREQUENCY): A frequency at which coherent electromagnetic radiation of energy is useful for communication purposes. Also, the entire range of such frequencies.

RF PATTERN: A term used to describe a fine herringbone pattern in a picture which is caused by a high-frequency interference. This pattern may also cause a slight horizontal displacement of scanning lines, which results in a rough, or ragged, vertical edge on the picture.

RINGING: An oscillatory transient occurring in the output of a system as a result of a sudden change in input.

RIPPLE: Amplitude variations in the output voltage of a power supply caused by insufficient filtering.

ROLL: A loss of vertical synchronization which causes the picture to move up or down on a receiver or monitor.

ROLL-OFF: A gradual decrease in gain-frequency response at either or both ends of the transmission pass band.

TAP: Any device used to obtain signal voltages from a coaxial cable. The earlier forms, such as capacitive and transformer types, have been replaced by directional couplers in modern systems.

TASO: Television Allocations Study Organization.

TEARING: A term used to describe a picture condition in which groups of horizontal lines are displaced in an irregular manner.

TELEVISION CHANNEL: A band of frequencies 6 MHz wide in the television broadcast band and designated either by number or by the extreme lower and upper frequencies.

TELEVISION TRANSMISSION STANDARDS: The standards which determine the characteristics of a television signal as radiated by a television broadcast station.

TERMINATION: A term used in reference to impedance matching the end of cable runs by installing a non-inductive resistor having the same resistance value as the characteristic impedance of the cable.

TEST PATTERN: A chart prepared for checking the overall performance of a television system. It contains various combinations of lines and geometric shapes. The camera is focused on the chart, and the pattern is viewed on a monitor.

TILT: Difference in level between Channels 2 and 13 at the output of the amplifier in dB; in fully-tilted system operation, equal to slope. See also full-tilt, half-tilt, and flat outputs.

TILT COMPENSATION: The action of a tilt-compensated gain control, whereby tilt of amplifier equalization is simultaneously changed with the gain so as to provide the correct cable equalization for different lengths of cable; normally specified by range and tolerance.

TRANSIENTS: Signals which exist for a brief period of time prior to the attainment of a steady-state condition. These may include overshoots, damped sinusoidal waves, etc.

TRAP: A selective circuit used to attenuate undesired signals while not affecting desired signals.

SATURATION (COLOR): The vividness of a color. Saturation is directly related to the amplitude of the chrominance signal.

SAWTOOTH WAVEFORM: A waveform resembling the teeth of a saw; such a waveform has a slow or sloping rise time and a short fall-time.

SCANNING: The process of moving the electron beam of a pickup tube or a picture tube across the target or screen area of a tube.

SELECTIVITY: The characteristic which determines the extent to which the desired frequency can be distinguished from other frequencies.

SIGNAL STRENGTH: The intensity of the signal measured in volts, millivolts, microvolts, or dBmV, which are dB's referred to 1 millivolt across 75 ohms.

SIGNAL-TO-NOISE RATIO (1) (GENERAL): The ratio of the level of the signal to that of the noise. Notes: (A) This ratio is usually in terms of peak values in the case of impulse noise and in terms of the root-mean-square values in the case of random noise. (B) Where there is a possibility of ambiguity, suitable definitions of the signal and noise should be associated with the term; as, for example: peak-signal to peak-noise ratio; root-mean-square signal to root-mean-square noise ratio; peak-to-peak signal to peak-to-peak noise ratio, etc. (C) This ratio may often be expressed in decibels. (D) This ratio may be a function of the bandwidth of the transmission system. (2) (CAMERA TUBES): The ratio of peak-to-peak signal output current to root-mean-square noise in the output current. (3) (TELEVISION TRANSMISSION): The signal-to-noise ratio at any point is the ratio in decibels of the maximum peak-to-peak voltage of the video television signal, measured at the synchronizing pulse tips to the root-mean-square voltage of the noise.

SLOPE: Difference in amplifier gain, or change in cable attenuation, between Channels 2 and 13, in dB. Distinguished from "tilt" in that tile refers to signal level differences, while slope refers to device characteristics.

SNOW: Heavy random noise.

SPAN: Distance between amplifiers in the trunk or distribution systems; also, distance between taps.

SPLITTER: A network supplying a signal to a number of outputs which are individually matched and isolated from each other.

STANDARD MINIMUM SIGNAL: 1000 microvolts across 75 ohms (0 dBmV) in RF systems; 0.7 Vp-p noncomposite. 1 Vp-p composite in video systems.

STREAKING: A term used to describe a picture condition in which objects appear to be extended horizontally beyond their normal boundaries.

SUB-CHANNELS: The channels between video and 54 MHz, also known as sub-band frequencies.

SUPPRESSION: The reduction of undesired signals to an acceptable level.

SYNC: A contraction of "synchronizing" or "synchronize."

SYNC COMPRESSION: The reduction in the amplitude of the sync signal with respect to the picture signal.

SYNC LEVEL: The level of the peaks of the synchronizing signal.

SYNC SIGNAL: The signal employed for the synchronizing of scanning.

SYNCHRONIZATION: The maintenance of one operation in step with another.

SYSTEM LEVEL: The level of the highest signal frequency at the output of each amplifier. Must be carefully chosen and maintained for least distortion and noise.

TELEVISION BROADCAST BAND: The frequencies in the band extending from 54 to 800 MHz which are assignable to television broadcast stations. These frequencies are 54 to 72 MHz (Channels 2 through 4), 76 to 88 MHz (Channels 5 and 6), 714 to 216 MHz (Channels 7 through 13), and 470 to 890 MHz (Channels 14 through 83).

UHF (ULTRA HIGH FREQUENCY): In television, a term used to designate the frequencies corresponding to Channels 14 through 83.

UNDERSHOOT: The initial transient response to a unidirectional change in input which precedes, and is opposite in sense to, the main transition.

VELOCITY OF PROPAGATION: Velocity of signal transmission. In free space, electromagnetic waves travel with the speed of light; in coaxial cables, this speed is reduced. Commonly expressed as percentage of the speed in free space.

VERTICAL RETRACE: The return of the electron beam to the top of the picture tube screen or the pickup tube target at the completion of the field scan.

VERTICAL RESOLUTION: The number of horizontal lines that can be seen in the reproduced image of a television pattern.

VESTIGIAL SIDEBAND TRANSMISSION: A system of transmission where the sideband on the lower side of the carrier is partially suppressed.

VHF (VERY HIGH FREQUENCY): In television, a term used to designate the frequencies corresponding to Channels 2 through 13.

VIDEO: A term pertaining to the bandwidth and spectrum position of the signal produced by a television camera.

VIDEO BAND: The frequency band utilized to transmit a composite video signal.

VIDEO AMPLIFIER: A wideband amplifier used for passing picture signals.

VISUAL CARRIER FREQUENCY: The frequency of the carrier which is modulated by the picture information.

Vp-p (VOLTAGE PEAK-TO-PEAK): Voltage amplitude measured from the highest positive peak to the highest negative peak in one cycle.

VSWR: Abbreviation for Voltage Standing Wave Ratio. Reflections present in a cable due to mismatch (faulty termination) combine with the original signal to produce voltage peaks and dips by addition and subtraction. The ratio of the peak-to-dip voltage is termed VSWR. A perfect match with zero reflections produces a VSWR of 1. For freedom from ghosting, most matches in a CATV system must have a VSWR of 1.25 or less.

WAVEFORM MONITOR: An oscilloscope designed especially for viewing the waveform of a video signal.

WHITE CLIPPER: A circuit designed to limit white peaks to a predetermined level.

WHITE COMPRESSION: Amplitude compression of the signals corresponding to the white regions of the picture; results in differential gain.

WHITE PEAK: The maximum excursion of the picture signal in the white direction.

WIDTH: The size of the picture as measured in the horizontal direction.

WINDSHIELD WIPER EFFECT: Result of cross-modulation, where the horizontal sync pulses of one of more TV channels are superimposed on the desired channel carrier. Both black and white windshield wiping are observed and are caused by different mechanisms. See also countermodulation.

APPENDIX II

The material in this section is taken from The Federal Register, Vol. 37, No. 30, Saturday, Feb. 12, 1972, pp. 3290-3292.

Subpart K—Technical Standards

§ 76.601 Performance tests.

(a) The operator of each cable television system shall be responsible for insuring that each such system is designed, installed, and operated in a manner that fully complies with the provisions of this subpart. Each system operator shall be prepared to show, on request by an authorized representative of the Commission, that the system does, in fact, comply with the rules.

(b) The operator of each cable television system shall maintain at its local office a current listing of the cable television channels which that system delivers to its subscribers and the station or stations whose signals are delivered on each Class I cable television channel, and shall specify for each subscriber the minimum visual signal level it maintains on each Class I cable television channel under normal operating conditions.

(c) The operator of each cable television system shall conduct complete performance tests of that system at least once each calendar year (at intervals not to exceed 14 months) and shall maintain the resulting test data on file at the system's local office for at least five (5) years. It shall be made available for inspection by the Commission on request. The performance tests shall be directed at determining the extent to which the system complies with all the technical standards set forth in § 76.605. The tests shall be made on each Class I cable television channel specified pursuant to paragraph (b) of this section, and shall include measurements made at no less than three widely separated points in the system, at least one of which is representative of terminals most distant from the system input in terms of cable distance. The measurements may be taken at convenient monitoring points in the cable network: *Provided*, That data shall be included to relate the measured performance to the system performance as would be viewed from a nearby subscriber terminal. A description of intruments and procedure and a statement of the qualifications of the person performing the tests shall be included.

(d) Successful completion of the performance tests required by paragraph (c) of this section does not relieve the system of the obligation to comply with all pertinent technical standards at all subscriber terminals. Additional tests, repeat tests, or tests involving specified subscriber terminals may be required by the Commission in order to secure compliance with the technical standards.

(e) All of the provisions of this section shall become effective March 31, 1972.

§ 76.605 Technical standards.

(a) The following requirements apply to the performance of a cable television system as measured at any subscriber terminal with a matched termination, and to each of the Class I cable television channels in the system:

(1) The frequency boundaries of cable television channels delivered to subscriber terminals shall conform to those set forth in § 73.603(a) of this chapter: *Provided, however*, That on special application including an adequate showing of public interest, other channel arrangements may be approved.

(2) The frequency of the visual carrier shall be maintained 1.25 MHz±25 kHz above the lower boundary of the cable television channel, except that, in those systems that supply subscribers with a converter in order to facilitate delivery of cable television channels, the frequency of the visual carrier at the output of each such converter shall be maintained 1.25 MHz±250 kHz above the lower frequency boundary of the cable television channel.

(3) The frequency of the aural carrier shall be 4.5 MHz±1 kHz above the frequency of the visual carrier.

(4) The visual signal level, across a terminating impedance which correctly matches the internal impedance of the cable system as viewed from the subscriber terminals, shall be not less than the following appropriate value:

Internal impedance:
 75 ohms.
 300 ohms.
Visual signal level:
 1 millivolt.
 2 millivolts.

(At other impedance values the minimum visual signal level shall be $\sqrt{0.0133\,Z}$ millivolts, where Z is the appropriate impedance value.)

(5) The visual signal level on each channel shall not vary more than 12 decibels overall, and shall be maintained within

(i) 3 decibels of the visual signal level of any visual carrier within 6 MHz nominal frequency separation, and

(ii) 12 decibels of the visual signal level on any other channel, and

(iii) A maximum level such that signal degradation due to overload in the subscriber's receiver does not occur.

(6) The rms voltage of the aural signal shall be maintained between 13 and 17 decibels below the associated visual signal level.

(7) The peak-to-peak variation in visual signal level caused undesired low frequency disturbances (hum or repetitive transients) generated within the system, or by inadequate low frequency response, shall not exceed 5 percent of the visual signal level.

(8) The channel frequency response shall be within a range of ±2 decibels for all frequencies within −1 MHz and +4 MHz of the visual carrier frequency.

(9) The ratio of visual signal level to system noise, and of visual signal level to any undesired cochannel television signal operating on proper offset assignment, shall be not less than 36 decibels. This requirement is applicable to:

(i) Each signal which is delivered by a cable television system to subscribers within the predicted Grade B contour for that signal, or

(ii) Each signal which is first picked up within its predicted Grade B contour.

(10) The ratio of visual signal level to the rms amplitude of any coherent disturbances such as intermodulation products or discrete-frequency interfering signals not operating on proper offset assignments shall not be less than 46 decibels.

(11) The terminal isolation provided each subscriber shall be not less than 18 decibels, but in any event, shall be sufficient to prevent reflections caused by open-circuited or short-circuited subscriber terminals from producing visible picture impairments at any other subscriber terminal.

(12) Radiation from a cable television system shall be limited as follows:

Frequencies	Radiation limit (microvolts/meter)	Distance (feet)
Up to and including 54 MHz	15	100
Over 54 up to and including 216 MHz.	20	10
Over 216 MHz	15	100

(b) Cable television systems distributing signals by using multiple cable techniques or specialized receiving devices, and which, because of their basic design, cannot comply with one or more of the technical standards set forth in paragraph (a) of this section, may be permitted to operate provided that an adequate showing is made which establishes that the public interest is benefited. In such instances the Commission may prescribe special technical requirements to ensure that subscribers to such systems are provided with a good quality of service.

(c) Paragraph (a)(12) of this section shall become effective March 31, 1972. All other provisions of this section shall become effective in accordance with the following schedule:

	Effective date
Cable television systems in operation prior to March 31, 1972	Mar. 31, 1977
Cable television systems commencing operations on or after March 31, 1972	Mar. 31, 1972

§ 76.609 **Measurements.**

(a) Measurements made to demonstrate conformity with the performance requirements set forth in §§ 76.701 and 76.605 shall be made under conditions which reflect system performance during normal operations, including the effect of any microwave relay operated in the Cable Television Relay (CAR) Service intervening between pickup antenna and the cable distribution network. Amplifiers shall be operated at normal gains, either by the insertion of appropriate signals or by manual adjustment. Special signals inserted in a cable television channel for measurement purposes should be operated at levels approximating those used for normal operation. Pilot tones, auxiliary or substitute signals, and nontelevision signals normally carried on the cable television system should be operated at normal levels to the extent possible. Some exemplary, but not mandatory, measurement procedures are set forth in this section.

(b) When it may be necessary to remove the television signal normally carried on a cable television channel in order to facilitate a performance measurement, it will be permissible to disconnect the antenna which serves the channel under measurement and to substitute therefor a matching resistance termination. Other antennas and inputs should remain connected and normal signal levels should be maintained on other channels.

(c) As may be necessary to ensure satisfactory service to a subscriber, the Commission may require additional tests to demonstrate system performance or may specify the use of different test procedures.

(d) The frequency response of a cable television channel may be determined by one of the following methods, as appropriate:

(1) By using a swept frequency or a manually variable signal generator at the sending end and a calibrated attenuator and frequency-selective voltmeter at the subscriber terminal; or

(2) By using a multiburst generator and modulator at the sending end and a demodulator and oscilloscope display at the subscriber terminal.

(e) System noise may be measured using a frequency-selective voltmeter (field strength meter) which has been suitably calibrated to indicate rms noise or average power level and which has a known bandwidth. With the system operating at normal level and with a properly matched resistive termination substituted for the antenna, noise power indications at the subscriber terminal are taken in successive increments of frequency equal to the bandwidth of the frequency-selective voltmeter, summing the power indications to obtain the total noise power present over a 4 MHz band centered within the cable television channel. If it is established that the noise level is constant within this bandwidth, a single measurement may be taken which is corrected by an appropriate factor representing the ratio of 4 MHz to the noise bandwidth of the frequency-selective voltmeter. If an amplifier is inserted between the frequency-selective voltmeter and the subscriber terminal in order to facilitate this measurement, it should have a bandwidth of at least 4 MHz and appropriate corrections must be made to account for its gain and noise figure. Alternatively, measurements made in accordance with the NCTA standard on noise measurement (NCTA Standard 005-0669) may be employed.

(f) The amplitude of discrete frequency interfering signals within a cable television channel may be determined with either a spectrum analyzer or with a frequency-selective voltmeter (field strength meter), which instruments have been calibrated for adequate accuracy. If calibration accuracy is in doubt, measurements may be referenced to a calibrated signal generator, or a calibrated variable attenuator, substituted at the point of measurement. If an amplifier is used between the subscriber terminal and the measuring instrument, appropriate corrections must be made to account for its gain.

(g) The terminal isolation between any two terminals in the system may be measured by applying a signal of known amplitude to one and measuring the amplitude of that signal at the other terminal. The frequency of the signal should be close to the midfrequency of the channel being tested.

(h) Measurements to determine the field strength of radio frequency energy radiated by cable television systems shall be made in accordance with standard engineering procedures. Measurements made on frequencies above 25 MHz shall include the following:

(1) A field strength meter of adequate accuracy using a horizontal dipole antenna shall be employed.

(2) Field strength shall be expressed in terms of the rms value of synchronizing peak for each cable television channel for which radiation can be measured.

(3) The dipole antenna shall be placed 10 feet above the ground and positioned directly below the system components. Where such placement results in a separation of less than 10 feet between the center of the dipole antenna and the system components, the dipole shall be repositioned to provide a separation of 10 feet.

(4) The horizontal dipole antenna shall be rotated about a vertical axis and the maximum meter reading shall be used.

(5) Measurements shall be made where other conductors are 10 or more feet away from the measuring antenna.

§ 76.613 Interference from a cable television system.

In the event that the operation of a cable television system causes harmful interference to reception of authorized radio stations, the operation of the system shall immediately take whatever steps are necessary to remedy the interference.

§ 76.617 Responsibility for receiver-generated interference.

Interference generated by a radio or television receiver shall be the responsibility of the receiver operator in accordance with the provisions of Part 15, Subpart C, of this chapter: *Provided, however,* That the operator of a cable television system to which the receiver is connected shall be responsible for the suppression of receiver-generated interference that is distributed by the system when the interfering signals are introduced into the system at the receiver.

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15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report is concerned with the delivery of broadband information between the system head-end and the individual subscriber terminals. Recommendations pertaining to the need for research in specified areas are given. A review of the system hardware is provided, including discussion of device noise and distortion characteristics. Treatment is given to various types of trunking systems, including two-way configurations. A discussion of the applications of advanced communications techniques is provided, covering digital transmission, multiple-access systems, and signal transmission via optical waveguides. Finally, a review and listing of standards and tests for the delivery system are given, including FCC and NCTA standards.

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